PHYSICAL LAWS AND EFFECTS

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CREATIVE ENGINEERING PROGRAM

PHYSICAL LAWS AND EFFECTS

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An Engineer who utilizes only the commonly known physical laws and effects tends to limit himself to conventional engineering practice. This compilation contains many uncommon phenomena which may be valuable in the solution of your problems. Brief descriptions, illustrations, magnitudes, and references have been provided for each law and effect. The entire collection is indexed alphabetically by (1) name, (2) physical quantities involved, and (3) field of science.

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The Long View

There is an old Scotch tale about a teacher known for his wisdom, and a student who decided to test it. The student caught a small bird and went to the teacher's home.

"I will ask him if the bird in my hand is alive," he thought. "If he says it is, I will crush it. If he says it is dead, I will release it."

But when he asked the teacher his question, the wise man said, "The choice is yours."

Products and industries, men and nations, grow not from one idea but from many. And ideas, in turn, do not come as flashes from space but as minute advances around an individual grain of experience or technical principle. By themselves they are valuable local improvements, but only that. But brought carefully together, sifted to remove the sound from the unsound, they become the basis for the kind of products upon which great industries are built.

Ideas are fragile. At each step of development they can die as easily as the bird in the student's hand, chiefly because the immediate possessor of them, or a person coming into contact with them, does not recognize their importance, or his influence over them.

It is at this point that industries become stronger or enter stagnancy through the value of the idea that is given or denied them; that careers advance or become static to the degree that a person has the ability to recognize progressive thinking and to see that it is applied most effectively.

In other words, ideas and sound thinking can be stifled or poorly utilized--or they can be weighed carefully and passed on to strengthen the base of technical knowledge and human progress.

Laws and Effects and How to Use Them

by C. F. Hix, Jr.

New products, new inventions, and whole new industries are being created out of old dusty text books! Wide-awake men in the technical world are making these startling advances - simply by searching out discarded and forgotten physical laws and effects. For example, the magneto-striction phenomena was written off as a laboratory curiosity in 1926. Today, it has been applied to Sonar, strain gages, phonograph pickups, and dust precipitation. Recent work in atomic physics and semi-conductors has brought dozens of laws and effects back to life.

More and more present day problems are demanding a completely new approach or invention in order to provide a real contribution to the art. A fruitful area to search for these new ideas is among the multitude of unheralded phenomena existing in nature. But a serious barrier arises: how can information be obtained on little known laws and effects?

Some inventors keep a card file of all the effects they hear about. One person has over 300 effects in his file. The primary source of this material is the early editions of old physics books. Even the later texts have an astounding repertoire, though they tend toward more general presentations. Of course, the latest additions to this field of knowledge are found in the current scientific journals. Technical dictionaries provide a broad coverage of their own particular field. But none of these sources gives a complete or convenient coverage. Unfamiliar and unapplied laws and effects are scattered and buried among a mountain of books and magazines.

This volume was compiled so that a thorough search of laws and effects could become a practical part of the engineering approach to problems. The entire collection has been indexed and cross referenced so that pertinent information may be located rapidly. There are a few techniques which will assure maximum results in the use of this book.

First of all, the difference between a law and an effect should be recognized. An effect is a reaction in nature that occurs when a certain stimulus is supplied. Usually, the exact reasons connecting this cause and effect are not easily understood. The data on most effects is still empirical and is difficult to handle in a mathematical analysis. Semi-conductors and photo emissive effects fall into this category.

A law is an interpretation of one or more effects and is generalized to make a complete understanding possible. Problems involving laws can be treated analytically. Galileo described the speed of a falling body as proportional to time squared. Newton further generalized on Galileo's observation and stated the law of gravitation.

An excellent technique for applying laws and effects to a problem is to break the problem down into input and output physical quantities. For instance, a light signal input and a temperature variation output may be desired. First, try bridging the gap directly with any known effect. If this is unsuccessful, think of a number of physical quantities that are suggestive as intermediate steps. Light might be connected to resistance to current to heat. These steps may be connected with as many different phenomena as can be recalled from memory. A number of semi-complete paths will result: each with a different link missing. A renewed search of unfamiliar laws and effects is certain to complete one or more of these links.

The Cross Reference by Physical Quantities provides an easy means for searching out these links between input and output quantities. The volume can be entered by two other channels: the Index and the Cross Reference by Fields of Science. The Index serves the purpose of a technical dictionary. Even though the laws and effects are alphabetically arranged, the Index should be consulted since there are often many different names for the same effect. The Cross Reference by Fields of Science permits a clearer picture to be gained of a particular field.

Mr. Albert Hansen, Jr., of the Meter and Instrument Department, recently carried to fruition a development which demonstrates the application of laws and effects. He was assigned the problem of developing a precision potentiometer of the self-balancing servo type. After studying the prior art, he determined that a superior form of DC to AC converter would be a substantial technical contribution to the art. Converters employed by others in the field in nearly every case used contacts to convert the low level d-c error signal (about 10^{-13} watts) to a-c for amplification. Mr. Hansen made a search of all known laws and effects involving physical quantities that could be used to modulate a low level d-c signal. The Hall effect was found and offered a distinct possibility, provided materials were available with a sufficiently high Hall constant. (See "Hall effect" in the text.) Tellurium was first found in the literature to have the highest coefficient available. By one of those fortunate accidents that befall a person earnestly seeking an answer, data was found on germanium in connection with mobility studies in semi-conductors that showed it to have an extremely high Hall coefficient. Immediately a sample of germanium was obtained and a model constructed that proved to be superior to any known method of d-c to a-c conversion. The result was an entirely static device. A fundamental U.S. patent has been issued on this converter.

The possibilities for new applications of a law are never exhausted. Electrostatic paint spraying uses Coulomb's Law: the object to be painted is one electrode, the paint gun the other. Now, a scheme is being developed to spray oil into a furnace by the same method, eliminating the air blower used for atomization of fuel. Only through development engineers having an undominable curiosity, imagination and perseverance coupled with a background of laws and effects will our "old chestnuts" ever be cracked. Among these old problems one can find the need for an inexpensive magnetic amplifier, cooling methods for electrical equipment, a new time keeper, an accelerometer, a substitute for a relay, etc; the list seems to have no limit.

A knowledge of laws and effects demands a recognition of exceptions and limitations. The exceptions are just as valuable as the rule. As an example, the inverse temperature resistance characteristic of certain materials is used to make thermistors and to provide protective circuits in electric blankets. The unusual temperature resistance behavior near absolute zero has already been applied outside the laboratory.

Limitations, on the other hand, present serious pitfalls to the unwary. The failure to investigate and analyze orders of magnitude can lead to many wasted development dollars. For instance, the Peltier effect states that a junction of two dissimilar metals will absorb heat when current flows through the joint in the proper direction. This suggests the possibility of a refrigerator with no moving parts. However, as the current flow is increased to get more cooling, the generation of resistance heat becomes significant. The net result is that the junction will cool only a few degrees below ambient under the best conditions.

A good background in basic laws and effects has another more subtle advantage. Possible trouble areas can be foreseen in the early development stages of a project. The existence of a significant but unexpected effect is often discovered late in the testing stage of a development.

Any development minded engineer should give serious consideration to building a compilation of laws and effects for himself. This type of information can only be collected over a period of years through constant awareness of its presence. No two people's interests are exactly alike, so one person may choose to collect from one area while the other may have need from some other field. If one could search out the effects in any one field, compile an explanation inter-relating them, illustrating them with examples, he would have a sound understanding of that field.

SUMMARY

Laws and Effects, to be of any value, must be collected and understood by the individual concerned. It is through the continued building of a background knowledge, well assimilated, that the mind can utilize the information in problem synthesis. A routine system can partially be substituted for the lack of background knowledge by use of the input-output, physical quantity approach to a problem. The actual utilization of this material can and does lead to the new products, the ingenious solutions and the patentable ideas.

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ABSORPTION

I. Description

All materials absorb all wave lengths of electromagnetic radiation to some extent. If the materials attenuate the radiation severely over a considerable frequency band, its absorption is general. If the absorption occurs primarily on narrow bands, the process is known as selective absorption.

As is true for all radiation, the energy is absorbed in quanta. The quanta absorbed may be used to change the energy of the material in several general ways:

1. A change in the nuclear state of the atom (gamma rays)
2. A shift in the quantum state of an electron (light, ultra-violet)
3. A change in the vibration amplitude of two nuclei (near infrared)
4. A change in the rotational kinetic energy of the molecule (far infrared)

The excited atoms lose their energy either by collision (heat) or re-radiation.

II. Illustration

The energy absorbed by a body is usually used to raise the temperature of the material. The energy reflected or transmitted, if in the visible region, is interpreted by the eye as color. Some unusual aspects of absorption are resonance radiation and fluorescence. Resonance radiation (primarily occurring in gases) is the scattering of the incident light in all directions as the material first absorbs the incident energy, then re-radiates some of it on the same wave length. This resonance radiation is very pronounced with sodium vapor. Fluorescence is the re-radiation of the energy on a longer wave length.

III. Magnitude

Very dilute solutions of some chemicals may strongly absorb narrow bands of frequencies, thus allowing a chemical analysis by optical means.

IV. References

1. Mac Dougall, Frank H., Physical Chemistry, The Macmillan Co., New York 1936, pp 202-206, Description of absorption.

See also: Stokes Law of Fluorescence

Lambert's Law
Wood & Ellett Effect

Quantities

Color
Frequency
Light, visible
Radiation
Wave Length
Material

ADSORPTION

I. Description

Adsorption is the ability of a material to hold a gas or liquid on its surface; this attraction may be molecular as with charcoal or capillary as with silica gel.

II. Illustration

Silica gel is used to remove water vapor from an atmosphere (dehydrator). Certain metals such as platinum black have the power to gather gases on their surface. Since this action is exothermic, platinum black has been used to ignite gas burners. Hydrogen adsorbed on platinum is electrically conducting and is used as a hydrogen electrode. Adsorption has also been used in some refrigerating systems. Of interest is the diamagnetism exhibited by adsorbed paramagnetic materials, even though the absorber (charcoal) may have been initially slightly paramagnetic.

III. Magnitude

For equilibrium between a gas or vapor and a solid the Freundlich equation applies:

$$x = AP^{\frac{1}{n}}$$

where x = the amount of gas adsorbed per unit solid
n = a constant (usually greater than 1)
P = the partial pressure of gas in equilibrium

IV. References

1. MacIntyre, H. J., Refrigeration Engineering, John Wiley & Sons, New York 1937, pp 203-4, Primarily a quantity discussion.

2. Mac Dougall, Frank H., Physical Chemistry, The Macmillan Co., New York, 1936, pp. 677-681. Treatments for liquids and solids.

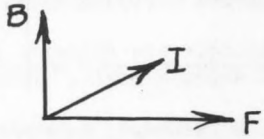
Quantities

Concentration
Capacity
Gas
Material
Molecules
Surface Tension

AMPERE'S LAW

I. Description

When a conductor carries an electric current in a magnetic field, there is a force on the conductor that is proportional to the current, the length of the conductor in the magnetic field, the magnetic flux density and the sine of the angle between the conductor and the magnet field. The force is at right angles to both the conductor and the magnetic field. A charged particle moving with some velocity V through a magnetic field acts the same as a current and will experience a force in the same manner.



Fleming's Rule relates flux, motion, and emf. The index finger, middle finger and thumb are placed at right angles to each other and represent flux, emf, and motion, respectively. If the right hand is used, these are the conditions as found in the generator, while the left hand is used to analyze behavior of a motor. The expression for the force of a current carrying conductor is as follows:

$$F = \frac{B\ I\ L \sin\theta}{10}$$

F = force in dynes
I = current in amperes
L = length in cm
B = flux density in gauss
θ = angle between V and L

This formula may be rewritten for use in motors: $T = K_t\ Z\ I_a\ \phi$

where: T = Torque
K_t = constant involving no. of paths, poles, and units
Z = no. of conductors on armature
I_a = current to armature
ϕ = flux from one north pole entering armature

The equivalent expression for the case of the moving charge is as follows:

$$F = \frac{V\ Q\ B \sin\theta}{10}$$

F = force in dynes
Q = charge in coulombs
V = velocity in cm per sec.
B = flux density in gauss
θ = angle between B and the velocity

II. Illustration

Ampere's Law can be used as a basis of measuring the current in a conductor. The conductor would be placed normal to the magnetic field of known flux density. The force, which could be measured by sensitive balance, would be proportional to the current in the conductor. The effect of the magnetic field on a moving charged particle is used by the mass spectrometer for chemical analysis.

III. Magnitude of Effect

If the current of one ampere flows in a conductor five cm. long normal to a field of ten thousand gauss, the conductor would experience a force of .011 lbs. (5000 dynes).

At Cambridge, Mass., the magnitude of the earth's field is .58 gauss. If, at this location, a single coil enclosing an area of 1 square meter had a current of 25 amperes circulated through it, the maximum torque due to the earth's field would be .001 lb. ft.

IV. References

1. Sears, F. W., Principles of Physics, Addison-Wessley Press, Inc., 1944, Vol 2 pg. 240

2. MIT Staff, Electrical Circuits, John Wiley & Sons, Inc., New York 1940

3. Hausmann, Erick, and Edgar Slack, Physics, D. Van Nostrand Co., Inc., New York 1939, pp 419-421, Force of Current Carrying Wire, page 428 Action of Field on Moving Charge.

4. Attwood, Stephen S., Electric and Magnetic Fields, John Wiley & Sons, Inc., New York 1941 pp 395-400. Field about a moving charge. Effect of relativity.

5. Richtmyer, F. K. and E. H. Kennard, Introduction to Modern Physics, McGraw-Hill Book Co., Inc., New York 1947, pp 60-68. Field due to an accelerated charge.

Quantities

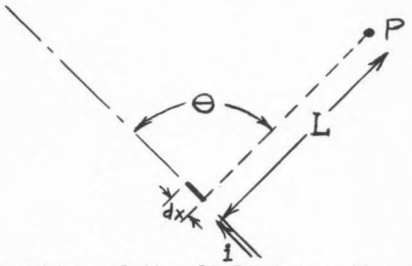
Force
Current
Length (of conductor)
Magnetic Flux
Charge
Velocity
Angle
Voltage

AMPERE'S (BIOT-SAVART) LAW (1820)

I. Description

Ampere's Law furnishes the basis for the solution of low frequency problems relating to the magnetic fields produced by electric currents. Since a magnetic field exists in a region where a magnetic pole experiences a mechanical force, it may be concluded that whenever a current of electricity flows, a magnetic field exists in the region of the current and it is possible to measure the value of the field by placing a magnet in that region. The field intensity (H) is by definition equal to the force per unit magnetic pole (F ÷ M).

However, to compute the field intensity at some point (P) due to a current (i) following any path, it is desirable to know the portion of the intensity at (P) due to the current in an element (dx) of the path. Since it is impossible to isolate an element of current, Ampere formulated the following mathematical relation entirely on the basis of experience and reasoning:



$$dH_p = \frac{i\,dx\sin\theta}{L^2}$$

H_p = field intensity at P (Oersteds)
i = current (amperes)
dx = element of current (cm)
L = distance from dx to P (cm)
θ = angle between direction of i and the line L

The direction of the field intensity at P is perpendicular to the plane which contains the element dx and line L (right hand rule Ampere's Law).

With this relation it is possible to determine field intensity existing at a point in the vicinity of a current following a known path by integrating over the current path.

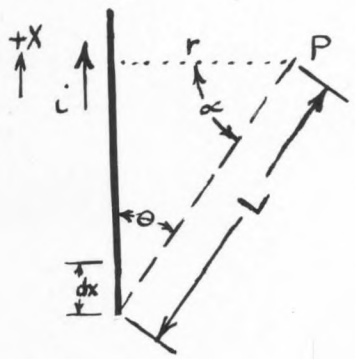
II. Illustration

The above relation is most applicable to the design of magnetic fields of a desired pattern. By the use of the so called Helmholtz coils a magnetic field may be obtained that is nearly uniform over a limited region near the center of the coil.

More familiar applications are electromagnets, solenoids, a number of electrical instruments, and magnetic deflection coils for television receivers.

III. Magnitude of the Effect

The magnetic intensity at a point due to a current flowing in straight wire of infinite length is given by:



$$H = \int_{-\infty}^{+\infty} \frac{i\,dx\sin\theta}{L^2}$$

But $x = r\tan\alpha$

$dx = r\sec^2\alpha\,d\alpha$

$$L = \frac{N}{\cos\alpha}$$

$$\sin\theta = \cos\alpha$$

$$H = \frac{i}{r}\int_{-\frac{\pi}{2}}^{+\frac{\pi}{2}} \cos\,d$$

$$H = \frac{2i}{r}$$

So, for i = 10 amps, r = cm

H = 0.2 oersteds

IV. References

1. Page, Lehigh, Introduction to Theoretical Physics, D. Van Nostrand Co., Inc., New York 1935 pp 426-444, Theoretical treatment of several cases.

2. Hausmann, Erick, and Edgar P. Slack, Physics, D. Van Nostrand Co., Inc., New York 1939 pp 412-416, A more elementary presentation than that of the first reference.

Quantities

Magnetic Field	Displacement (Linear)
Current	Angle between two quantities
Length (of conductor)	

ARCHIMEDES' PRINCIPLE (287-212 BC)

I. Description

A body immersed in a fluid experiences an upward force equal to the weight of the displaced fluid (either liquid or gas). The pressure exerted by fluids on surfaces in contact with them is perpendicular to each surface area element. The buoyant force is a static force on the body and is exerted upward and through the center of gravity of the displaced fluid. This point of action is called the center of buoyancy.

II. Illustration

A hydrometer gives a direct measure of the density of a fluid. The volume of the floating object that is submerged is directly proportional to the density of the fluid. The load capacity of balloons is limited by this principle.

III. Magnitude of Effect

It is possible by proper construction to obtain readings of four significant figures on even simple hydrometers.

IV. References

1. Hausmann, Erick, and Edgar P. Slack, Physics, D. Van Nostrand Co., Inc., New York 1939, pp 190, 192-193, and 223. The principles for both fluids and gases with examples.

Quantities

Density
Specific Gravity
Volume
Mass

ARRHENIUS THEORY OF ELECTROLYTIC DISSOCIATION

I. Description

Theory of electrolytic dissociation states that the molecule of an electrolyte can give rise to two or more electrically charged atoms or ions, i.e., particles are present in greater number than would be normally expected from the mass of substance dissolved, thereby causing an abnormally greater effect on the boiling points, freezing points, etc., observed in aqueous solutions of inorganic acids, bases and salts.

II. Illustration

The depression of freezing point of water by various materials is used to prevent the cooling systems of internal combustion engines from freezing during the winter months.

III. Magnitude

A molal (one gram molecular weight in 1000 cc H_2O) sugar solution (a non-electrolyte) freezes at -1.86°C., while on the other hand a molal solution of sodium chloride (an electrolyte) freezes at - 3.42°C. The theory applies fairly well to weak electrolytes.

IV. References

1. Mac Dougall, Frank H., Physical Chemistry, The Macmillan Co., New York 1936, pp 264-269. Theory and validity.

2. Dale, Malcolm, Principles of Experimental & Theoretical Electro-Chemistry, McGraw-Hill Book Co., Inc., New York 1935 pp 8-23. History and Description.

See also: Blagden's Law
Babo's Law

Quantities

Solution
Freezing Point
Boiling Point

BARKHAUSEN EFFECT

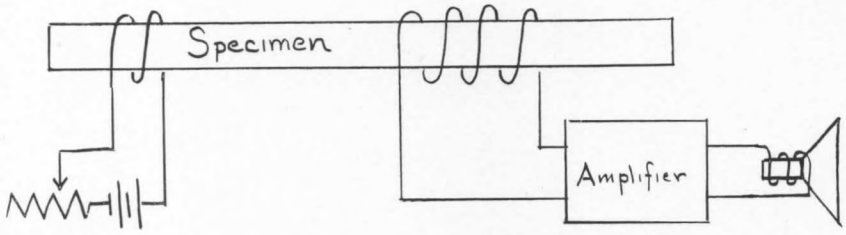
I. Description

Over the middle portion of the B-H curve of an iron sample, a stepwise build up of flux density "B" is observed as an applied field is smoothly increased in intensity. This build up is by finite jumps.

This effect is most readily explained by and used to substantiate the domain theory of magnetization. As the applied field is increased beyond very small values, the magnetic moments of individual domains are aligned in the direction of the preferred crystal axis nearest to that of the impressed field. This effect takes place, not by re-alignment of the domain as a rigid body, but by re-alignment of the axis of the spins of the individual electrons within the domain from one stable direction to another stable direction. Throughout any one domain, this re-alignment of spins takes place simultaneously.

II. Illustration

The fact that the change in magnetization occurs in jumps can be observed by means of a loud speaker connected to a coil surrounding the specimen. Each reorientation of a domain suddenly changes the flux through the pickup coil and causes a click in the loud speaker.



III. Magnitude of the Effect

The jump in flux density per any one step is in the order of 10^{-6} gauss. The effect is strongest in single crystals of silicon steel.

IV. References

1. Bozorth, R. M., Present Status of Ferromagnetic Theory, A.I.E.E. Transaction, 1935, Vol. 54, pp. 1251-1261. Review of magnetic theory and progress.

2. M. I. T. Staff, Magnetic Circuits & Transformers, John Wiley & Sons, Inc., New York, 1947, p. 11-12. Limitations of Barkhausen effect.

Quantities

Magnetic Flux
Noise

BAUSCHINGER EFFECT

I. Description

This effect is the low deformation resistance in compression following a tensile pre-strain. This effect is greater at room than at higher temperatures.

II. Illustration

This effect may be noticed during a series of tests where compression follows the application of a tensile stress. The material does not follow the usual stress-strain curve immediately upon the application of the load.

III. Magnitude

Upon re-application of the load to the specimen, the strain may be as much as 0.1% greater than expected (for copper). This effect deals with plastic deformation.

IV. References

1. Lubahn, J. D., The Bauschinger Effect in Creep and Tensile Tests on Copper, General Electric Research Lab Report No. RL-872, Research Publications Services, The Knolls, Schenectady, N. Y. Experiments with copper.

Quantities

Displacement, linear
Elastic limit
Force
Strain and Stress
Temperature

BERNOULLI THEOREM

I. Description

At any point along a tube through which a liquid is flowing, the sum of the pressure plus the potential energy due to position plus the kinetic energy remain constant (friction being disregarded).

If no external forces, other than gravity, act on the unit of volume considered then its total energy must remain constant. Expressed mathematically:

$$H = h + \frac{P}{\rho g} + \frac{v^2}{2g}$$

P = static pressure (dynes per cm^2)
ρ = density ($grams/cm^3$)
v = velocity (cm per second)
H = total head (cm)
g = gravitational constant (cm per $second^2$)
h = elevation above datum plane (cm)

Torricelli's Law may be derived from this:

$$v_B^2 = 2g\,(h_A - h_B)$$

v_B = velocity of eflux at point B (for a hole at B)
h_A = height of tank at A (top of liquid)
h_B = height of tank at B
or $h_A - h_B$ = fluid head available

II. Illustration

In hydraulics, the three terms of the first three members of the Bernoulli Equation are called respectively the "elevation head", the "pressure head", and the "velocity head". Bernoulli's Law states that if the flow takes place without any external interference, that is without doing work or having work done on it, then the total head H remains unchanged throughout the flow; a fact which follows from the principle of conservation of energy. Use is made of this Bernoulli Effect in a venturi to measure flow; also, air foils obtain lift because of this theory. Some forms of liquid helium violate this law.

III. References

1. Hausmann, Erick, and Edgar P. Slack, Physics, D. Van Nostrand Co., New York 1939, pp 206-210, derivation, statement, and use.

2. Page, Lehigh, Introduction to Theoretical Physics, D. Van Nostrand Co., New York 1935, pp 222-224, derivation and mathematics.

Quantities

Altitude
Pressure
Density
Velocity, linear
Flow

BOLTZMANN DISTRIBUTION LAW

I. Description

For a substance in thermal agitation, only part of the atoms or molecules will be in any one quantum state:

$$N_t = C\, w_t e^{-\frac{E_t}{kT}}$$

Where: N_t = average number in energy state
C = constant of proportionality
w_t = number of states at same energy level
E_t = energy of state
k = Boltzmann's constant 1.381×10^{-16} ergs/degree
T = absolute temperature °K

II. Illustration

The proportion of excited atoms may be calculated with the above equation. Sodium, excited to the D lines in a flame at 1800°C, has w = 6 or six states in the upper level. For the normal level w = 2. These two levels are hf = 3.36×10^{-12} ergs apart. This gives

$$\frac{N_1}{N_o} = 3e^{-\frac{(E_1 - E_o)}{kT}} = 3e^{-\frac{3.36 \times 10^{-12}}{2073 \times 1.38 \times 10^{-16}}} = 2.3 \times 10^{-5}$$

Thus, only a small proportion of the sodium atoms emit light.

III. References

1. Richtmyer, F. K. and E. H. Kennard, Introduction to Modern Physics, McGraw Hill Book Co., Inc., New York 1947, pp 231-233. A description of the special case illustrated.

Quantities

Energy
Radiation
Temperature

BREIT-WAGNER THEORY (DISPERSION THEORY)

I. Description

This theory deals with the absorption of neutrons by atomic nuclei. The probability of capture for a neutron by a nucleus is increased if the energy of the neutron is near one of the energy levels of the nucleus.

II. Illustration

This phenomenon is much the same for neutrons as resonance radiation is for electrons. If an atom is excited by light of the same frequency which it emits, then a scattering of the incident beam, or resonance occurs. (Wood & Ellett Effect). Cadmium shows a strong absorption for neutrons with an energy of 0.176 electron volts. The absorption of these neutrons is about 1000 times that for 10 electron volt neutrons.

III. Magnitude

The ability of a material to absorb neutrons is roughly inversely proportional to the energy of the neutron. This is especially true for boron which follows the law for neutrons with energies of 0.01 to 1000 electron volts.

IV. Reference

1. Glasstone, Samuel, Sourcebook on Atomic Energy, D. Van Nostrand Co., Inc., New York, 1950. pp 313-315. Qualitative description, and general examples.

Quantities

Energy
Velocity, linear

BREMSTRAHLUNG RADIATION

I. Description

Continuous spectra X-rays are produced whenever electrons are slowed down by an absorbing medium. This effect may be predicted from Maxwell's equations.

II. Illustration

The production of X-rays by ordinary X-ray tubes or by a betatron illustrates the use of this phenomena.

III. Magnitude

The proportion of the energy of the electron which is converted into radiation is increased as the initial energy of the electron increases and also with the atomic number of the target material. Bremstrahlung radiation occurs even for gases as target materials.

IV. Reference

1. Glasstone, Samuel, Sourcebook on Atomic Energy, D. Van Nostrand Co., Inc., New York, 1950, pp 106-166. Description and some effects.

Quantities

Acceleration
Density
Electric Field
Energy
Frequency
Radiation
Voltage
X-rays

BREWSTER'S LAW

I. Description

For some angle of reflection from a surface, the reflected and refracted rays contain a maximum of polarized light. This angle of incidence, or the polarizing angle, is the one for which the refracted and reflected rays are at right angles. The tangent of the polarizing angle for a substance is equal to the index of refraction. If n is the index of refraction and ϕ is the polarizing angle:

$$n = \tan \phi$$

II. Illustration

The reflection from a series of thin glass plates is used to produce light which has a high degree of polarization (about 50%). The reflection of light from roads (glare) is largely polarized parallel to the road or horizontally, making vertically polarized sun glasses useful to eliminate this glare.

III. Magnitude

For glass with a refractive index of 1.5, the theoretical reflection factor for light polarized in the plane of incidence is 0.148, while that for light polarized perpendicular to the plane of incidence is 0. Apparently Brewster's Law does not hold exactly to this because reflection is not completely a surface phenomena. However, six or seven glass plates produce light about 50% polarized.

IV. References

1. Preston, Thomas A., The Theory of Light, MacMillan & Co., Ltd., London 1928, pp 345-6. Law and polarization by reflection.

2. Walsh, John W. T., Photometry, D. Van Nostrand Co., New York, 1926, pp 112-114. Calculation of amount and polarization of light reflected.

Quantities

Angle, refraction
Polarization
Angle, reflection
Wave Length
Frequency

Chemistry
General Physics

BROWNIAN MOVEMENT

I. Description

The Brownian movement is seen in colloidal solutions and is supposed to furnish evidence of molecular motion. Small, visible, colloidal particles are knocked about by colliding with the invisible molecules like footballs in the midst of a crowd of invisible players.

When a colloidal solution is viewed through an ultramicroscope, points of light are seen, due to particles, which show a trembling or vibrating movement. This was observed first by Mr. Brown, a botanist.

II. Illustration

The Brownian movement has been used to determine Avogadro's number.

III. Magnitude

A microscope is necessary to observe this motion, the maximum particle size for which this motion can be observed being approximately .001 mm.

IV. References

1. Ephrain, Fritz, Inorganic Chemistry, translated by P. C. L. Thorne and E. R. Roberts. Interscience Publishers, Inc., New York 1946, pp 99-111. Relation Brownian movement and Avogadro's number.

2. Mac Dougall, Frank H., Physical Chemistry, The Macmillan Company, New York 1936, pp 673-675. Relation of Brownian movement and Avogadro's number.

Quantities

Temperature
Motion

CAPACITY/DIELECTRIC

I. Description

Capacitance is measured by the charge which must be communicated to a body to raise its potential one unit. Electrostatic unit capacitance is that which requires one electrostatic unit of charge to raise the potential one electrostatic unit. The farad = 9×10^{11} electrostatic units. A capacitance of one farad requires one coulomb of electricity to raise its potential one volt. Dimensions - electrostatic system,

(El) ; or $(\mu^{-1}l^{-1}t^{2})$ for the electromagnetic system. (μ = permeability)

The capacity of a condenser is directly proportional to the dielectric constant of the material separating the conducting surfaces. The dielectric constant of some materials vary with frequency and temperature.

Geometry	Capacity (farads)	Symbols
Any body	$C = Q/V$	C = Capacitance Q = Charge V = Volts
Spherical conductor	$C = 4\pi Er$	E = Dielectric constant
Two concentric spheres	$C = \frac{4\pi E r_1 r_2}{r_2 - r_1}$	r = Radius
Two concentric cylinders	$C = \frac{2\pi E s}{\log_6 \frac{r_2}{r_1}}$	s = Distance between or length
Parallel plates	$C = \frac{A E}{s}$	A = Area

These formulas give capacitance in farads if dimensions are in meters and $E = \frac{E_r}{36\pi 10^9}$ where E_r = dielectric constant of the material relative to free space.

These formulas give capacitance in electrostatic units if the dimensions are in cm. and if $E = \frac{K}{4\pi}$ is used, where K = dielectric constant of the material (free space = 1).

II. Illustration

This effect is used to measure fluid heights. The variation of the dielectric constant between the plates as the fluid level changes is interpreted as a variation in liquid height.

III. Magnitude

The maximum variation of dielectric constant is from several thousand for barium titanate to one for free space.

The change in dielectric constant with frequency may be 3:1 or more, again this large variation being for ceramic materials.

The variations of dielectric constant with temperature may be 3:1 or more, some types of barium titanate ceramics being very sensitive.

IV. References

1. Attwood, Stephen S., Electric & Magnetic Fields, John Wiley & Sons, Inc., New York 1941, pp 70-71, 139-140, 62, 68, 81, 82, 151. Formulas and their derivations for capacitance of simple shapes.

2. Kaplyanski, A.E., Methods for the Design of Electrical Devices With Non-Linear Dielectrics, Elecketrichestvo No. 1, 1953, pp 44-48. Summary appearing in The Engineers Digest, July 1953, Vol. 14, No. 7. pp 257-260, London, The Design and use of non-linear dielectric materials.

Quantities

Charge
Capacitance
Voltage
Dielectric Constant
Displacement, linear
Temperature
Thickness

CAVITATION

I. Description

If a pressure change occurs in a fluid so that the local pressure is below the vapor pressure, a bubble of the vapor is formed. This process, the bubble formation, and its subsequent collapse (often violent) is termed cavitation. The local high transient pressures and temperatures produced in cavitation are responsible for most of the observed effects.

II. Illustration

Cavitation may be produced by motion such as ship propellors, or by sound waves in fluids. Electrical discharges occur because of the potential differences built up on opposite sides of the cavity. Sonoluminescense, the production of light by sound (occurs feebly in water), may result from ultrasonic cavitation in liquids. Some immiscible combinations may be emulsified by cavitation.

III. Magnitude

In water, the hammering action of the cavities collapsing may give rise to local pressures of thousands of atmospheres and temperatures of several hundred degrees. In distilled water 0.03 watts/cm^2 or pressure variations of $\pm$ 0.3 atmospheres are required to produce cavitation.

IV. References

1. Weissler, Alfred, Sono-chemistry: The Production of Chemical Changes With Sound Waves, The Journal of the Acoustical Society of America, Vol. 25, No. 4, July 1953, pp 651-657. A good survey, mainly concerned with chemical reactions.

2. Willard, G. W., Ultrasonically Induced Cavitation in Water: A Step by Step Process, The Journal of the Acoustical Society of America, Vol. 25, No. 4, July 1953, pp 669-686. A qualitative discussion.

Quantities

Energy
Motion
Pressure
Temperature
Vapor Pressure
Vibration
Sound

CHRISTIANSEN EFFECT

I. Description

When finely powdered transparent substances, such as glass or quartz, are immersed in a liquid of the same index of refraction, maximum transparency can be obtained only for monochromatic light. If white light is employed the transmitted color corresponds to the particular wave length for which the two substances, solid and liquid, have exactly the same index of refraction. Due to differences in dispersion the indices of refraction of the solid and liquid will match for only a narrow band of the spectrum.

II. Illustration

When illuminated by the proper color light, a transparent glass or plastic object will become invisible when immersed in a liquid of the same refractive index. Since the refractive indices of some liquids change with temperature, this effect may be used as a temperature detector as well as a selective filter.

III. Magnitude

As an example of the temperature sensitivity of this type filter, crown glass particle in liquid methyl benzoate transmits red light at 64°F and blue light at 122°F. Magnesia powder films may be used in the infra red. Appreciable transmission occurs for bandwidths of about 1000 angstrom units.

IV. References

1. Koller, Lewis R., Ultraviolet Radiation, John Wiley & Sons, Inc., New York, 1952 p 173. Use of this effect to construct filters.

2. Strong, John, Procedures in Experimental Physics, Prentice-Hall, Inc., New York, 1945 pp 372-375. Construction, uses and limitations of Christiansen filter.

Quantities

Wave Length
Temperature
Color
Light, visible

COMPTON EFFECT (1923)

I. Description

When an X-ray collides with an electron it bounces off with reduced energy in another direction.

The effect may be explained by the use of the quantum theory of light. The single X-ray photon, acting as a material particle, may collide with an electron and recoil as though it were a perfectly elastic sphere. Applying the law of conservation of energy to the collision, it is assumed that the energy ($\frac{1}{2}$ mv^2) imported to the recoiling electron must be supplied by the incident X-ray quantum (hf_o). Having lost energy the X-ray moves off in some new direction with lower frequency (f_1) and energy (hf_1). Applying conservation of energy we have:

$$hf_o = hf_1 + \tfrac{1}{2} mv^2$$

where: hf_o = energy of X-ray before impact
hf_1 = energy of X-ray after impact
m = mass of the electron (should be corrected for relativistic effects)
v = velocity of recoiling electron

II. Magnitude of the Effect

For X-rays that are scattered at an angle of 90°, the observed or calculated change in wave length amounts to 0.243 angstrom and is the same for all X-ray wave lengths.

III. Reference

1. Richtmyer, K. H. and E. H. Kennard, Introduction to Modern Physics, McGraw-Hill Book Co., Inc., 1947 pp 514-522. A qualitative and quantitative description.

Quantities

Wave Length
X-rays

CONSTANT HEAT CAPACITY LAW*

I. Description

The product of the atomic weight and the specific heat for the solid state has approximately the same value for most elements. This empirical law is approximately true only for solids, the mean constant being 6.4.

II. Illustration

The chief variations are the non-metallic elements with low atomic weight. Examples are:

Element	C	H	B	Be	Si	O	P	S	Ge
Atomic Heat	1.8	2.3	2.7	3.7	3.8	4.0	5.4	5.4	5.5

III. Magnitude

This law holds fairly well for elements with atomic weights greater than 40. Some of these elements which agree well with this law are:

Silver	6.03
Gold	6.25
Copper	5.88
Lead	6.52
Iron	6.12
Uranium	6.61

The product is also affected by temperature, the value increasing with increasing temperature.

IV. References

1. Richtmyer, F. K. and E. H. Kennard, Introduction to Modern Physics, McGraw-Hill Book Co., Inc., New York 1947 pp 424-438. A discussion (mathematical and otherwise) of specific heats.

2. Friend, J. Newton, A Textbook of Physical Chemistry, Vol. 1, J. B. Lippincott Co., Philadelphia, 1933. pp 216-221. Violations of the law and some explanation.

*Other names are:

Du Long & Petit's Law
Atomic Heat
Atomic Heat Capacity

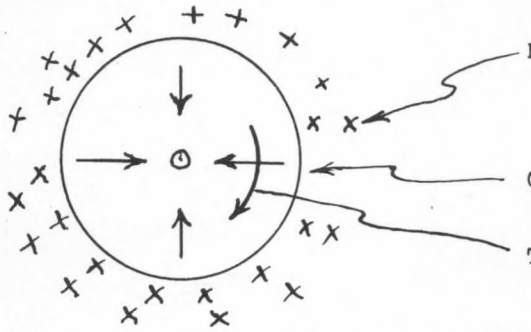
Quantities

Atomic Weight
Specific Heat

CORBINO EFFECT

I. Description

If a circular disk that is carrying a current radially is placed at right angles to a magnetic field, a current component is seen to flow around the disk.



This is generally considered a special application of the Hall Effect.

II. Illustration

The Corbino Effect decreases for bismuth at higher flux densities. The effect may cause current in either direction, antimony being the reverse of bismuth in its effect. The effect is independent of the thickness of the disc. For iron, nickel, cobalt, bismuth and antimony, the effect is not proportional to the field. This effect has been observed for two electrolytes in contact, i.e., poured one on top of the other.

III. Magnitude of the Effect

$$C = \frac{cBI}{2} \frac{\ln (r_2)}{(r_1)} \text{ amps}$$

where
- C = circular current in amps
- c = Corbino constant in gauss^{-1}
- I = total radial current flow in amps
- r_1 = inner radius of disk
- r_2 = outer radius of disk
- B = magnetic field density in kilogauss

For several metals

Material	B	c x 10^{-7}
Copper	2.82	-3.36
	7.31	-2.38
Iron	1.39	+7.45
	8.45	+7.13
Aluminum	7.97	-.77
Bismuth	.03	-711.0
	2.63	-613.0
	7.72	-381.0

IV. References

1. Campbell, L. L., Galvanomagnetic & Thermomagnetic Effects, Longmans, Green & Co., N.Y., 1923, pp 125-137. Relates Hall Effect and Corbino Effect, details of apparatus, and constants.

2. Washburn, Edward W. (Editor), International Critical Tables, Volume VI, McGraw-Hill Book Co., Inc., New York, 1929. pp 415-419. Diagram and tables of constants.

Quantities

Current
Length
Magnetic Flux
Material

COSMIC RAYS

I. Description

Cosmic rays are high energy particles (believed to be protons) which are extra-terrestrial in origin.

Latitude Effect - The intensity of cosmic rays is a minimum at the equator, maximum at the poles. This variation follows the geomagnetic latitude, but there is essentially no change in intensity for latitudes greater than 50°. The effect is caused by the earth's magnetic field which screens the equatorial regions from all rays having less than 15 Bev (billion electron volts), but for latitudes greater than 50°, only 4 Bev are needed. Particles with energy of less than 4 Bev cannot reach the earth because of the influence of the magnetic field of the sun. This change in intensity with latitude is about 10% at sea-level and 90% at the top of the atmosphere.

East-West Effect - Because of the magnetic field of the earth, and the charge of the cosmic rays (positive), more particles approach from the West than the East.

Altitude Effect - The intensity of cosmic rays increases to an altitude of about 50,000 ft., after which it starts to decrease. The incoming rays (hard rays) react with the atmospheric gases producing secondary particles (soft cosmic rays) which first increase the total intensity with decreasing altitude. The absorbing effect of the atmosphere then starts to be important, and decreases the total intensity. The variation with altitude from sea-level to maximum may be 35 to 1. The intensity of the hard rays increases with increasing altitude.

Showers - Showers are produced by either hard or soft cosmic rays reacting with the matter through which they are passing. First the incident particle jars loose a number of other particles which in turn release more. The multiplication process continues until the energy level decreases enough so that the radiation is absorbed by the material. Showers are produced by lead, the thickness for maximum effect for this material being 2 cm. Large showers occur in the air, there being about one each hour 1000 ft. or more across and about one a week covering a mile diameter area.

Bursts - A sudden increase in apparent cosmic ray activity caused by showers from the walls or shielding of the detector or the disintegration of a nucleus close enough to the chamber to send some decomposition products through the detector.

Stars - The tracks left by the pieces of a disintegrating nucleous expelling products in several directions. There may be from 2 to 10 or more branches, the average number being 3 or 4.

II. Reference

1. Glasstone, Samuel, Sourcebook on Atomic Energy, D. Van Nostrand Co., Inc., New York, 1950, pp 475-484. Aspects of cosmic rays and some experiments. 489-496, Cosmic ray phenomena.

Quantities

Position (geographical)
Altitude
Angle, incidence
Concentration
Direction
Energy
Radiation

COULOMB'S LAW

I. Description

The electrostatic attraction or repulsion between two charged bodies is proportional to the magnitude of these charges and inversely proportional to the square of the distance between them.

This may be expressed by the equation:

$$F = \frac{Q_1 Q_2}{\mathcal{E} r^2}$$

Where: F = force in dynes
$\mathcal{E}$ = dielectric constant
Q = charge in stat-coulombs
r = distance in cm

This same law applies for two isolated magnetic poles with the strength of the poles used instead of charge and permeability instead of dielectric constant. Using masses instead of charges, the equation becomes Newton's Law of gravitation where

$$\frac{1}{\mathcal{E}} = 6.66 \times 10^8 \frac{cm}{gm\text{-}sec^2}$$

II. Illustration

Coulomb's law can be used as a method of measuring voltage electrostatically. This has the advantage that it requires no current for its operation. One such device uses the voltage to force a charge on two gold leaves that are connected together at the top. The sign of the charge on both leaves is the same and they separate at the bottom. The angle the leaves make with each other is a measure of the voltage. The effect is also used in the production of Lichtenberg's figures, or more recently Xerographic printing.

III. Magnitude of the Effect

Two equal charges, each 10^{-6} coulombs, separated by a distance of 10 cm. would produce a force of 9×10^4 dynes of each other if in a vacuum.

Some values of dielectric constant

Material	$\mathcal{E}$
water (pure)	81
air (0°C and 760 mm)	1.0006
mica	5.8
rubber	2.5
barium & strontium titanates (near Curie temp.)	10,000

High values of dielectric constant may be obtained from a number of ferro-electric crystals.

IV. References

1. Page, Leigh, Introduction to Theoretical Physics, D. Van Nostrand Co., Inc., New York 1935, pp 357-359. A mathematical treatment.

2. Attwood, Stephen S., Electric & Magnetic Fields, John Wiley & Sons, Inc., New York 1941, pp 19, 195, 197. Coulomb's Law for charges and poles, pp 395-400. Relativistic effects on field of moving charge.

Quantities

Force
Charge
Displacement, linear
Dielectric Constant
Magnetic Flux

CURIE-WEISS LAW

I. Description

All ferro-magnetic substances have a definite transition temperature at which the phenomena of ferro-magnetism disappears and the substance becomes merely para-magnetic. This temperature is called "Curie Point" and is usually lower than the melting point.

The susceptibility of the para-magnetic substance above the Curie Point varies inversely as the temperature above that point. At or below the Curie Point, the Curie-Weiss Law does not hold.

$$I = \frac{A}{T} H$$

where: H = magnetic field intensity
I = resultant intensity of magnetization
T = temperature
A = Curie-Weiss constant

(can be used for para-magnetic substances)

The permeability of certain nickel-base alloys varies with temperature. With increasing temperature this variation may be almost anything, depending on the material.

II. Illustration

The change in permeability of the material with temperature may be used to control the temperature of an area, or the inductance of a circuit. Permanent magnetic circuits, such as in electric meters, may be compensated for temperature errors by suitable magnetic shunts.

Since a change in permeability also causes a change in volume, glass to metal seals are made to have the same expansion coefficient by using Kovar, whose total expansion coefficient due to both heat and permeability is made the same as the glass to which it is sealed.

III. Magnitude

With a choice of alloys, the variation of permeability with temperature may be made large -- as high as 100:1 for a 50°C change.

The Curie temperature may be from below 0°C to 800°C.

IV. References

1. Bhatmayer, S.S., and K. N. Mather. Physical Principles and Applications to Magneto-chemistry, MacMillan & Co., Ltd., London 1935, pp 144-150. Derivation of Curie-Weiss Law.

Quantities

Temperature
Magnetic Flux
Material

DEBYE FREQUENCY EFFECT

I. Description

The conductance of an electrolyte will increase with the frequency of the applied voltage.

II. Illustration

This effect ties together the frequency of the applied voltage, conductance of the fluid, the volume mobility, and concentration of the ions. This relation is especially true for the weak electrolytes such as acetic acid.

III. Magnitude

Since the equation for the effect is complicated, see reference No. 1 for the equations. The magnitude of this effect is less than that found for the Wien Effect.

IV. Reference

1. Dale, Malcolm, Principles of Experimental and Theoretical Electro-Chemistry, McGraw-Hill Book Co., Inc., New York 1935, pp 117-118, A brief discussion of the effect with equations.

Quantities

Concentration
Current
Frequency
Material
Resistance, electrical
Solution
Electrolysis

DIFFRACTION

I. Description

The spreading of a beam of energy into the region behind an obstacle is known as diffraction. This applies to all traveling wave phenomena.

II. Illustration

Diffraction gratings employing this principle are used in spectroscopy. The phenomena is also used to study crystal lattices by the use of X-rays. Bragg's equation has been derived for X-ray:

$$n\lambda = 2d \sin \phi$$

Where: n = an integer
λ = wave length of radiation
d = distance between atomic planes
ϕ = angle of refraction of rays from planes

Other examples of diffraction are Fresnel fringes which may be used to determine the diameter of small wires.

III. Magnitude

This phenomena limits the resolving power of lenses as expressed by the formula:

$$\theta = \frac{1.22\lambda}{D}$$

Where: θ = limiting angle of resolution
λ = wave length of the radiation
D = diameter of the lens

IV. References

1. Hausmann, Erick, and Edgar P. Slack, Physics, D. Van Nostrand, Inc., 250 Fourth Ave., New York 1939, pp 687-696, A qualitative and quantitative discussion for slits, lenses, gratings, and crystals.

2. Richtmyer, K. H. and E. H. Kennard, Introduction to Modern Physics, McGraw-Hill Book Co., Inc., New York 1947, pp 468-479. Bragg's equation and uses.

3. Page, Leigh, Introduction to Theoretical Physics, D. Van Nostrand Co., Inc., New York 1935, pp 582-603. Diffraction results theoretically derived for a number of cases.

4. Preston, Thomas A., The Theory of Light, MacMillan & Co., Ltd., London 1928. pp 242-334. Diffraction lines - how produced; diffraction gratings, calculations, how made; prism; some uses.

5. Sugg, Ronald E., An Interferometer for Examining Polished Surfaces, Mechanical Engineering, Volume 75, No. 8, August 1953. pp 629-631. Industrial use of interferometer.

Quantities

Wave Length
Angle, reflection
Displacement, linear
X-rays
Color
Frequency
Light, visible
Radiation
Sound

DOPPLER-(FIZEAU) EFFECT (1842)

I. Description

The wave length of a disturbance of fixed frequency may be altered if motion is imparted to the source or receiver of the disturbance. Under such circumstances, the change of wave length results in an alternation of the observed frequency. Somewhat different is the change in the observed frequency produced when the observer is in motion.

Four distinct cases result. The first if the observer is in motion, the second if the source is in motion, and third if both the source and observer are in motion, and fourth is the result of a moving reflector.

A. Observer in Motion

If velocities of motion are uniform and referred to the velocity of the medium, the following equation holds:

$$n^1 = n\left(1 \pm \frac{V_e}{S}\right)$$

Where: n^1 = frequency heard by observer
n = frequency of the source
V_e = velocity of the observer
S = distance traveled by the disturbance in one second

The negative sign indicates motion of the observer away from the source, the positive sign indicates motion of the observer toward the source.

B. Motion of the Source

If velocities of motion are uniform and referred to the velocity of the medium, the following equation exists:

$$n^1 = n\,\frac{S}{S \pm V_e}$$

Sign Convention and symbols same as in A

C. Both Source and Observer in Motion

If velocities of motion are uniform, and the velocity of the medium is considered, the following equation holds:

$$n^1 = n\left[1 \pm \frac{(\pm V_e - V_b)}{S \pm V_m \pm V_b}\right]$$

Where: V_b = velocity of the source
V_e = velocity of the observer
V_m = velocity of the medium

D. Stationary Source and Observer, Moving Reflector

If the velocities of motion are uniform and referred to the velocity of the medium, the equation for a moving reflector is:

$$n^1 = n\left[\frac{S}{S \pm V_e}\right]$$

This is sometimes known as the Belopolsky effect. For light, when a beam is reflected from moving mirrors and analyzed spectroscopically, the spectral lines are displaced.

II. Illustration

Radiating atoms in gases electrically excited to luminescence show the Doppler effect due to the random distribution of their speeds about an average, resulting in a certain widening of the spectral lines.

The change in pitch of the tone of a bell or horn on a passing train is explained by the Doppler Effect.

II. Illustration (Cont.)

In the tracking of guided missiles and rockets, a signal is transmitted by a ground station to the rocket. The rocket transmits back a signal at twice the frequency of the ground signal. This response signal transmitted from the rocket is received at several ground stations along with the ground signal. The two signals are beat together and the change in frequency as the rocket moves with respect to the various ground stations is recorded. With this information, the rocket is tracked on all three coordinates. A computer solves the necessary equations to furnish a point by point plot of the path of the rocket.

III. Magnitude of the Effect

At moderate velocities, the results indicated by the Doppler equations are experimentally verified. Application extends all the way from sound waves to radiated energy. Experiments on the Doppler effect as associated with light have verified the equations listed. However, in experiments dealing with light, it is not possible to distinguish between the equation of a moving source or that of a moving observer. Relativistic equations may, at times, be necessary, for all electromagnetic radiation.

IV. References

1. Richtmyer, F. K., and E. H. Kennard, Introduction to Modern Physics, McGraw-Hill Book Co., Inc., 1947, pp 397-398. Doppler effect on width of spectral lines.

2. Page, Leigh, Introduction to Modern Physics, D. Van Nostrand Co., Inc., New York 1935, pp 618-19, Doppler effect on light frequency.

3. Hausmann, Erick and Edgar P. Sound, Physics, D. Van Nostrand Co., Inc., New York 1934, pp 556-557. Three cases for sound.

Quantities

Frequency
Light, visible
Motion
Radiation
Velocity, linear
Wave Length
Sound

ELASTIC LIMIT

I. Description

Elastic limit is the maximum stress to which a body may be subjected without causing permanent deformation.

II. Illustration

This stress limit is the one used in designing structural members.

The elastic limit is used indirectly to determine the hardness of a material. In a Rockwell hardness tester, a conical diamond stylus has its pointed end forced into the surface of a material, and then the force is released. The depth of plastic penetration is used as a measure of surface hardness. A Brinell hardness tester does much the same thing, except a steel ball is used.

Springs stressed above this limit, change their properties.

III. Magnitude

Loads of 150 kg. are applied to the Rockwell diamond cone and the penetration is only a few thousandths of an inch.

For some common materials, the yield strengths (permanent set of 0.1%) are:

	Yield Strength
Aluminum (cold rolled)	18,770 lbs/in^2
Cast Iron	6,000
Magnesium, drawn, annealed	12,000
Phosphor Bronze	59,310
Steel, spring tempered	130,000

IV. Reference

1. Faires, I. V. M., Design of Machine Elements, The Macmillan Co., New York, 1946, Chapter I

See also: Hooke's Law

Quantities

Strain and Stress
Material

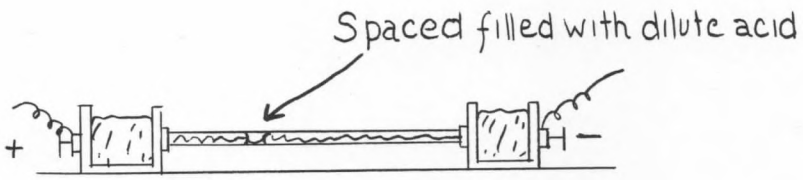
ELECTROCAPILLARITY

I. Description

The surface tension between two conducting liquids in contact, such as mercury and dilute acid, is sensibly altered when an electric current passes across the interface. As a result, when the contact is in a capillary tube, the pressure difference across the meniscus is affected by a current traversing the capillary column, the amount depending upon the magnitude and direction of the current across this boundary.

II. Illustration

This effect has been utilized in different forms of capillary electrometers. In the Dewar type, two small vessels of mercury are joined below the mercury level by a horizontal capillary tube, the mercury in which is interrupted by a short space filled with dilute acid. Upon applying a small potential difference to the two bodies of mercury, the equilibrium is disturbed and the drop of acid moves toward the low-potential end until the resultant capillary pressure is balanced by the hydrostatic pressure of the mercury.



Capillary Electrometer

III. Magnitude of the Effect

Since this effect is approximately proportional to the potential difference, the apparatus described above serves as a sensitive indicator for potentials as low as 0.003 volts.

IV. References

1. Glasstone, S., Textbook of Physical Chemistry, D. Van Nostrand Co., Inc., New York, 5th Edition, 1943. p 1203.

2. Atkinson, E., Translation of Ganot's Physics, William Wood & Co., New York, 1910, pp 992-4. A qualitative description.

3. Dole, Malcolm, Principles of Experimental & Theoretical Electro-Chemistry, McGraw-Hill Book Co., Inc., New York, 1935. pp 466-478. Examples, thermo-dynamics and theory of the phenomena.

Quantities

Pressure
Voltage
Surface Tension
Flow

Fluid Mechanics
Electricity & Magnetism
Chemistry

ELECTRO-KINETIC PHENOMENA

I. Description

Electro-osmosis (electro-endosmosis) is the movement of a polar fluid or an electrolyte by an electric current through a porous diaphragm. The converse is also true. The movement of a liquid through a porous diaphragm induces a voltage (streaming potential) across the diaphragm proportional to the pressure difference.

Cataphoresis is essentially the same phenomena as electro-osmosis. Instead of a fluid passing through a small capillary, suspended colloids, acting as the capillary walls, move in a direction reverse to that of the fluid. This effect does not exist for higher voltages. The inverse of cataphoresis is also true; particles settling produce an e.m.f. The effect is very sensitive to particle composition.

II. Illustration

The principle may be used as a flow meter or a transducer.

The electro-osmotic pressure developed for a number of fluids is proportional to the dielectric constant of the fluid:

$$\frac{P}{P_o} = \frac{K - K_g}{K_o - K_g}$$

Where: P = pressure of fluid
P_o = pressure of reference fluid
K = dielectric constant of fluid
K_o = dielectric constant of reference fluid
K_g = dielectric constant of tube (often glass)

III. Magnitude

The directions for the streaming current and fluid flow are the same, at least for water. The sensitivity may be 250 to 500 millivolts per psi. The voltage is affected by the concentration of the electrolyte, but is a linear function of pressure differences. This effect is used in the Cottrell precipitator (for dusts) as well as in the electro-deposition of materials such as rubber. For cataphoresis, some particle velocities are:

Dispersed Material	Particle Size	Velocity per 1 volt/cm
Quartz	1 μ	3 x 10^{-4} cm/sec
Gold	Below 100 $\mu\mu$	2.2
Platinum	" "	2.0
Ferric oxide	" "	3.0
Silver	" "	2.4
Iron	" "	1.9
Oil (emulsion)	About 2 μ	3.2
Air bubbles	About 0.1 mm	4

IV. References

1. E. Atkinson's translation of Ganot's Physics, William Wood & Co., New York 1910, pp 994-5, A qualitative discussion.

2. Hartway, Jr., E. V., Instruments, August 1953, Vol. 26, No. 8, Electro-kinetic Transducers, pp 1186-88, History, theory, application.

3. Mac Dougall, Frank H., Physical Chemistry, The Macmillan Co., New York 1936, pp 455-462. Mechanisms of transferance with numbers. pp 683-692 Electro-kinetic phenomena. Explanation and mathematics.

4. Dole, Malcolm, Principles of Experimental and Theoretical Electro-Chemistry, McGraw-Hill Book Co., Inc., New York 1935, pp 443-465. Electro-kinetic phenomena, history, explanation, and some uses.

Quantities

Acceleration
Current
Flow
Pressure
Voltage

EOTVOS EFFECT

I. Description

A postulate of Galileo-Newtonian mechanics is that a body moving East decreases in weight but increases in weight when going West.

This effect should be taken into account when measuring the force of gravity on the earth's surface.

II. Illustration

A pendulum on the surface of the earth will swing with a motion which is not exactly harmonic in the E-W direction, but its motion will be harmonic in a N-S direction.

III. Magnitude

The magnitude of the gravitational acceleration is

$$g = g_o - 2\Omega \cos \phi \frac{dy}{dt}$$

Where: g = effective gravity
g_o = gravitational acceleration
Ω = angular velocity of the earth
ϕ = geographical latitude
$\frac{dy}{dt}$ = velocity in rectangular coordinates with axes N & E

IV. References

1. Gray, Andrew, A Treatise on Gyrostatics and Rotational Motion, MacMillan & Co., Ltd., 1918 London, pp 523-4. The mathematical outline.

2. Science Abstracts Section A, Vol 23, Spon & Chamberlain, N. Y., 1920. Abstract No. 26 p 8, Abstract of article by Eotvos giving formula.

Quantities

Position, geographical
Weight
Velocity, linear

EXPANSION/TEMPERATURE OR THERMAL EXPANSION

I. Description

The coefficient of linear expansion or expansivity is the ratio of the change in length per degree C to the length at 0°C. The coefficient of volume expansion (for solids) is approximately three times the linear coefficient. The coefficient of volume expansion for liquids is the ratio of the change in volume per degree to the volume at 0°C. The value of the coefficient varies with temperature. The coefficient of volume expansion for a gas under constant pressure is nearly the same for all gases and temperatures and is equal to 0.00367 for 1°C.

Expansion/Temperature may be broken up into the expansion of solids, liquids and gases.

A. Expansion of Solids vs. Temperature

Solids expand linearly with temperature. The equation for this expansion in one direction is:

$$L_t = L_o (1 + \alpha t)$$

where L = length at temperature t (meters)
L_o = length at 0°C (meters)
α = Temperature coefficient of expansion (meters/meter - °C) (May be negative as for stretched rubber and silver iodide)
t = Temperature (°C)

At very low temperatures $\alpha \rightarrow 0$ for some materials.

B. Expansion of Liquids vs. Temperature

Liquids do not expand linearly with temperature. Their expansion is one hundred or more times that of a solid. The equation for the volumetric expansion of liquids is as follows:

$$V_t = V_o (1 + at + bt^2 + ct^3 \ldots)$$

where V_t = volume at temperature t (cu. ft.)
V_o = volume at 0°C (cu. ft.)
a = coefficient of expansion (cu. ft./cu. ft.-°C)
b = coefficient of expansion (cu.ft./cu.ft. -°C^2)
c = coefficient of expansion (cu. ft./cu.ft. -°C^3)
t = temperature (°C)

C. Expansion of Gases vs. Temperature

Gases expand five or ten times more than most liquids. Most gases have nearly the same coefficient of expansion. This coefficient is 1/273.18 of the gas volume per °C for an ideal gas assuming constant pressure. An ideal gas is defined as one which obeys Boyle's Law exactly and has a constant coefficient of expansion. The equation for the volumetric expansion of an ideal gas, assuming that pressure is constant, is as follows:

$$V_t = V_o (1 + at)$$

where: V_t = volume at temperature t (cu. ft.)
V_o = volume at °C (cu. ft.)
a = temperature coefficient (1/273.18 cu. ft./cu. ft. - °C)
t = temperature (°C)

II. Illustration

The mercury thermometer is a good example of this effect. A glass bulb containing a quantity of mercury is connected to a fine glass tube. A change in temperature varies the volume of the mercury and these small changes in volume show up as large variations of the length of mercury in the thin tube.

III. Magnitude of the Effect

A. Mercury has a linear expansion coefficient of 0.000030°C.
Mercury has a cubical expansion coefficient of:

$$a = .181 \times 10^{-3}$$

$$b = .0076 \times 10^{-6}$$

B. Steel has a linear coefficient of expansion of 0.000011 to 0.000015/°C.

C. Water has a cubical expansion coefficient of:

$$a = -6.43 \times 10^{-5}$$

$$b = 8.50 \times 10^{-6}$$

$$c = 6.79 \times 10^{-8}$$

IV. References

1. Michener, W. H., Physics for Students of Science and Engineering, John Wiley & Sons, Inc., New York, 1st Edition, 1947.

2. Hodgman, C. D., Handbook of Chemistry and Physics, Chemical Rubber Publishing Co., Cleveland, 1946, pp 1266-1276, 1745-1755. Tables of coefficients.

Quantities

Length
Displacement, linear
Temperature
Volume

FARADAY EFFECT (MAGNETO-OPTICAL ROTATION) (1845)

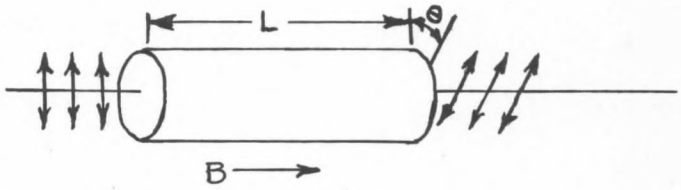
I. Description

When a magnetic field is applied to a transparent material through which plane polarized light is passed, there will be a rotation of the plane of polarization. This rotation is called the Faraday Effect and it is proportional to the length of material in the magnetic field, the strength of the magnetic field, the cosine of the angle between the magnetic field and the ray of light, and Verdet's constant.

This may be expressed by the equation:

$$\theta = V L B \cos \phi \left(\frac{n^2}{\lambda} \right) \left(n - \lambda \frac{dn}{d\lambda} \right)$$

Where: θ = angular rotation of plane of polarization in minutes of arc.
V = Verdet's constant
L = length in cm of material in the field
B = magnetic field intensity in gauss
ϕ = angle between H and direction of the light
n = index of refraction of the material
λ = wave length of light in free space



Verdet's constant is a function of temperature, the type of material, and is approximately proportional to the square of the frequency of the light. The rotation decreases with an increase in temperature. There is a time lag before this rotation after the application of the field.

II. Illustration

This effect could be used to detect the strength of an alternating magnetic field. Reflecting the beam back through the field and material doubles the effect. The specific rotation for many materials is little affected by the concentration of the solution.

III. Magnitude of the Effect

Verdet's constant for water at the sodium D line is approximately 0.013'/cm gauss. For glass (very heavy flint) V goes up to 0.09'/cm gauss for D line, both values for 20°C.

Temperature effect may be illustrated with water for which V =.0131 at 0°C and V =.0127 at 100°C.

Using 7 cm of very heavy flint glass, it would require a field of 100 gauss to give an angular rotation of 1°.

IV. References

1. Jenkins and White, Fundamentals of Physical Optics, McGraw-Hill Book Co., Inc., New York 1937.

2. Bhatmayer, S. S. and K. N. Mathur, Physical Principles and Applications of Magnetochemistry, MacMillan & Co., Ltd., London 1935, pp 251-271. Extensive discussion of many experiments with theory.

Quantities

Magnetic Flux
Displacement, angular
Length
Angle between two quantities
Index of Refraction
Polarization
Temperature
Frequency
Wave Length
Light, visible

FARADAY'S LAW OF ELECTROLYSIS - 1833

I. Description

A. First Law - Whenever an electric current passes across a junction between a purely metallic and a purely electrolytic conductor, a chemical change occurs, the amount of which, expressed in chemical equivalents, is exactly proportional to the quantity of electricity which passes. The equivalent weight is the amount of a substance liberated by a unit current for unit time.

B. Second Law - In electrolysis the quantities of the different substances which separate at the electrodes throughout the circuit are directly proportional to their equivalent weights, and are independent of the concentration and the temperature of the solution, the size of the electrodes, and all other circumstances. The voltage developed across the cell will vary with the concentration of the electrolyte and current.

II. Illustration

In electrolysis of many metallic salts, other than those of the alkali and alkaline earth metals, the metal is deposited at the cathode or negative junction between a metallic and an electrolytic conductor. Copper or lead is refined or deposited on another metal or graphite by electric deposition; nickel, silver, gold, zinc, cadmium, or chromium are deposited in electroplating on objects. Sodium and potassium may be electrolyzed through glass. For potassium this requires a lead and sodium free glass.

III. Magnitude of the Effect

96,500 coulombs of electricity will deposit 107.88 grams of silver or 31.8 grams of copper.

IV. References

1. Hausmann, Erick and Edgar P. Slack, Physics, D. Van Nostrand Co. New York 1939, pp 393-395. Discussion and sample calculations. pp 389-392 mechanism of electrolysis.

2. Hodgman, Charles D., Handbook of Chemistry and Physics, Chemical Rubber Publishing Co., Cleveland, Ohio 1946, pp 1946-8. Electro-chemical equivalents of the elements.

3. Dole, Malcolm, Principles of Experimental and Theoretical Electro-Chemistry, McGraw-Hill Book Co., Inc., New York 1935, pp 30-38. Electrolysis discussion.

Quantities

Weight
Current
Material
Electrolysis

FARADAY'S LAW OF INDUCTION

I. Description

If, for any reason, the number of lines of flux which thread through a conductor is altered, an electromotive force will be produced in the conductor during the change.

The line integral of the total electric field strength or intensity taken around any closed path is proportional to the negative rate of change, with respect to time, of the magnetic flux across any surface bounded by that path.

$$\oint \mathcal{E} \cdot dl = \frac{-d\,(B \cdot da)}{dt}$$

The common expression for an induced EMF in any circuit is proportional to the rate of change of the magnetic flux enclosed by the circuit:

$$E = -10^{-8}\, N\, \frac{d(\phi)}{dt}$$

where: E = volts
N = number of turns of the coil
ϕ = magnetic flux in maxwells enclosed by the coil
t = time in seconds

II. Illustration

The EMF is induced in the circuit regardless of the cause of the flux variation. The flux may change in magnitude or direction to produce a variation, or a conductor in the circuit may move through the lines of flux. The most common application of this law applies to rotating coils or windings having an EMF induced as they cut through a magnetic field. If A is the area enclosed by each coil, N is the number of coils, B is the magnetic flux density perpendicular to the axis of rotation and w is the angular velocity; then the peak value of induced EMF is:

$$V = NBAw$$

Lenz's Law illustrates this equation. When an electrical conductor forming a closed circuit or part of a closed circuit is moved in a magnetic field in such a way that a change takes place in the number of lines of magnetic induction passing through the circuit, a current is induced in the circuit and a mechanical force is set up such that this force tends to stop the motion which gave rise to the current.

Every action on a system, which in producing a change in its state, involves a transformation of energy, sets up reactions tending to preserve unchanged the configuration of the system.

Similarly when a conductor is moved in the presence of a magnet, induction comes into play and an EMF is set up between various parts of the block and causes currents of electricity to flow within it. These are known as eddy or Foucault currents.

The eddy current loss (Foucault current) in a core is the result of currents induced in the core by the varying magnetic flux. The magnitude of the power loss per unit volume is proportional to the square of the frequency, to the square of the flux density, inversely proportional to the resistivity of the core material, and directly proportional to the square of the thickness (or diameter) of the individual core laminations (or particles).

III. Magnitude of the Effect

At Cambridge, Mass., the magnitude of the earth's field is .58 gauss or 5800 maxwells/square meter. If a single coil enclosing an area of one square meter was rotated at 3600 rpm at this location, it could generate a peak EMF of 0.011 volts (on the strength of the earth's field alone).

IV. References

1. Page, Leigh, Introduction to Theoretical Physics, D. Van Nostrand Co., Inc., New York 1935. pp 457-460. A mathematical treatment.

2. Cohn, George I, Electromagnetic Induction, Electrical Engineering May 1949, American Institute of Electrical Engineers, New York. pp 441-447. An extensive evaluation of the applications of and exceptions to the various common formulae.

Quantities

Voltage	Velocity, angular	Current	Equilibrium
Magnetic Flux	Time	Energy	

FERRANTI EFFECT

I. Description

There are lengths of transmission lines and frequencies of transmitted electrical waves for which the line load voltage may be greater than the sending end voltage.

An expression can be derived which will give the open circuit end voltage of a transmission line wherein I_r (receiving end current) = 0. One such expression is:

$$V_{ro} = \frac{V_s \angle -\tan^{-1}(\tan b \tanh a)}{\sqrt{\sinh^2 a + \cos^2 b}}$$

where V_{ro} = receiving end voltage
V_s = sending end voltage
$S\sqrt{ZY} = a + jb = S(\alpha + j\beta)$
S = line length
Z = unit series impedance of the line
Y = unit shunt admittance of the line

Examining the equation, it can be seen that when $\sinh^2 a + \cos^2 b = 1$, V_{ro} is greater than V_s. As the line length increases $\sinh^2 a$ increases from zero to ever higher values. At the same time $\cos^2 b$ decreases from 1 to 0 and back to 1, etc. Thus for certain relatively short lines this effect is observed. This must be before $\sinh^2 a = 1$ because the lowest value $\cos^2 b$ can have is zero.

II. Illustration

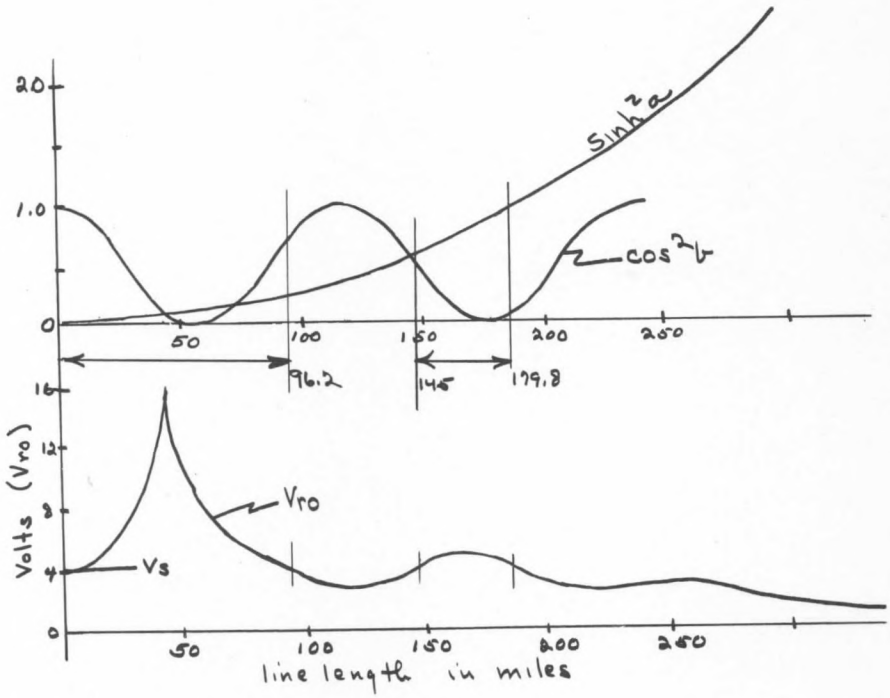
The Ferranti effect can be illustrated on a 165-mil diameter copper wire line with 12 inch spacing between the wires having the following parameters per loop mile:

R = 4.02 ohms
L = 3.37 mh
C = 0.00898 μf between wires
G = 5μ mhos

at 796 cycles per second

α = 0.0048 neper/mile
β = 0.0275 radius/mile
λ = 228.5 miles

Plotting V_{ro}, $\sinh^2 a$, and $\cos^2 b$



III. Magnitude of the Effect

The voltage gain by such an effect is limited only by the constants of the lines involved, and the open circuit conditions. The effect is frequency sensitive as might be expected since impedance is a function of frequency.

IV. Reference

1. Ware, L. A. and Reed, H. R., Communication Circuits, published by J. Wiley & Sons, Inc., New York, 2nd Edition, page 76

Quantities

Voltage Frequency Length

FICK'S LAW

I. Description

For a solution with non-uniform concentration, the diffusion of the solute from the regions of more to less concentration is at a rate proportional to the concentration gradient. This diffusion may be decreased by the application of a potential between regions of different concentration.

II. Illustration

When two liquids are carefully poured one on top of the other, they will duffuse according to this expression.

III. Magnitude

The expression for this law is:

$$\frac{dm}{dt} = -DS\frac{dc}{dx}$$

$\frac{dm}{dt}$ = mass of solute diffused per unit time

S = cross section area

$\frac{dc}{dx}$ = concentration gradient perpendicular to cross section

D = diffusion constant for solute and solution at a given temperature. For any one pair of substances, D is directly proportional to the absolute temperature and is not independent of the concentration for concentrated solutions.

$D = .312$ cm^2/day for cane sugar.

$D = \frac{RT}{W}$ R = gas constant; T = temperature (^oK); W = frictional resistance

IV. References

1. Dale, Malcolm, Principles of Experimental and Theoretical Electro-Chemistry, McGraw-Hill Book Co., Inc., New York, 1935. pp 137-148. Effect of an electric current on diffusion.

2. Eggert, John, Physical Chemistry (translated by S. J. Gregg), Constable & Co., Ltd., London 1932. pp 251-3. Fick's Law and some derivation.

See Also: Graham's Law

Quantities

Solutions
Time
Temperature
Area
Concentration
Voltage

FISSION

I. Description

Fission is the term used to describe a high energy transmutation process in which a nucleus breaks into two nuclei of approximately equal size as well as emits particles or radiation.

II. Illustration

Fission is usually induced by bombarding the nucleus with neutrons, protons, deuterons or gamma rays. The products of fission are not fixed, as uranium 235 may produce about 60 elements whose mass numbers vary from 72 to 150. While heavier elements seem to possess somewhat less stable nuclei, high energy particles have induced fission in some lighter elements such as bismuth, platinum, lead, thallium and tantalum. At least some of the fission products are radio-active.

III. Magnitude

Because fission liberates a relatively large amount of energy, the process is rather useful. In the fission of a uranium atom about 200 million electron volts are released, or the fission of one gram of uranium per day releases energy at a rate of 1 megawatt. This corresponds to the converting of about 0.1% of the mass into energy.

IV. Reference

1. Glasstone, Samuel, Sourcebook on Atomic Energy, D. Van Nostrand Co., Inc., New York, 1950. pp 258-9 definition, pp 344-409 history, mechanism uses.

Quantities

Atomic Weight
Energy
Radiation

GALVANO-MAGNETIC AND THERMO-MAGNETIC EFFECTS

(Hall, Ettingshausen, Nernst, and Righi-Leduc Effects)

If upon a thin, flat conducting plate of width b, thickness d, carrying a uniform constant longitudinal current (total current = I) of either electricity or heat, there be imposed normally a magnetic field of intensity H, there are set up two transverse and two longitudinal effects for either heat or electricity.

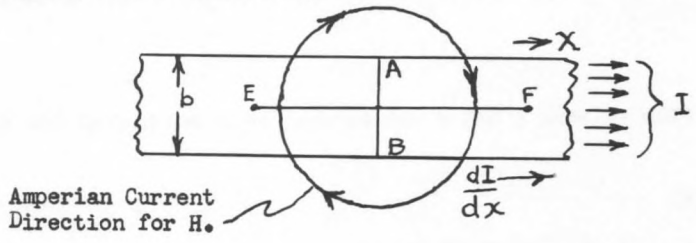


Figure I

In the absence of a magnetic field, AB is an equipotential or isothermal line.

HALL EFFECT

I. Description (see figure I)

When a current is flowing in a magnetic field, a voltage is developed at right angles to both the magnetic field and the current, and is proportional to the product of the intensity of the current, the magnetic flux and the sine of the angle between the current and the field. When either or both of the quantities mentioned above are varying, the instantaneous voltage would be proportional to the instantaneous values of the current and magnetic field. Near absolute zero a related photomagnetic effect is discernible. (See Photomagnetic Effects).

Hall Effect Coefficient = R (function of material and temperature)

$E_A - E_B = RH\ I/d$

d is the thickness of the material, parallel to H

II. Illustration

Measurement of the small output of a thermocouple is facilitated with this type of device. An alternating magnetic field is applied and an alternating voltage appears between A and B whose magnitude depends on the magnitude of I, and whose phase depends upon the direction of I. This a.c. signal may be easily amplified. This effect is also used to measure changes in a magnetic field.

III. Magnitude of the Effect

A) Bismuth

R = 6.9×10^{-8} volts - cm/ampere gauss at 15°C
R = 2.5×10^{-8} volts - cm/ampere gauss at 90°C

B) Tellurium

R = 60.0×10^{-8} volts - cm/ampere gauss at 15°C

C) Germanium

R = 8×10^{-5} volts - cm/ampere gauss at 25°C
R varies at a rate of - 0.1%/°C
Resistivity = 5.7 ohm cm at 25°C

See also Corbino Effect

ETTINGSHAUSEN EFFECT

I. Description

When an electric current flows across the lines of force of a magnetic field an electromotive force is observed which is at right angles to both the primary current and the magnetic field; a temperature gradient is observed which has the opposite direction to the Hall electromotive force.

Ettingshausen Coefficient = P

$T_A - T_B = P H I/d$

where: I = electric current

P is a function of material and probably of temperature. (This would require further investigation.)

II. Illustration

The temperature difference between A and B can be used as a measure of the current flowing in the material.

III. Magnitude of the Effect

A) Tellurium $P = 3 \times 10^{-4}$ °C/ampere meter

Supplementary Galvano-Magnetic Effects

The resistance between E and F increase (except for ferromagnetic materials) when the magnetic field increases. Maximum increase is of the order of 10%. (See Gauss Effect)

NERNST EFFECT

I. Description

When heat flows across the lines of magnetic force there is observed an electromotive force in the mutually perpendicular direction.

A) Nernst Effect Coefficient = Q

$E_A - E_B = - Q H b \frac{dT}{dx}$

where: $\frac{dT}{dx}$ = Temperature gradient

II. Illustration

Applying an alternating magnetic field would give a value of a.c. voltage that would be proportional to the temperature gradient.

III. Magnitude of the Effect

Tellurium $Q = 3.6 \times 10^{-9}$ volts/gauss °C

RIGHI-LEDUC EFFECT

I. Description

When heat flows across the lines of magnetic force there is a transverse temperature gradient.

A) Righi-Leduc Effect Coefficient = S

$T_A - T_B = - S H b \left(\frac{dT}{dx} \right)$

where: $\frac{dT}{dx}$ = temperature gradient

II. Illustration

The temperature difference between A and B is proportional to the quantity of heat flowing.

III. Magnitude of the Effect

A) Iron $S = 6 \times 10^{-7}$ gauss^{-1}

B) Tellurium $S = 62 \times 10^{-7}$ gauss^{-1}

Supplementary Thermo-Magnetic Effects

The thermo-resistance increases with increase of magnetic field intensity.

References:

1. Mason, W. P., W. H. Hewitt, and R. F. Wick, Hall Effect Modulation and Gyrators Employing Magnetic Field Independent Orientations in Termanium, Journal of Applied Physics, Vol. 24, No. 2, February 1953 pp 166-175. Use of Hall Effect to measure field strengths, modulate and to secure a non-reciprocal transmission.

2. Bhatnager, S. S. and K. H. Mathur, Physical Principles and Applications of Magneto-chemistry, MacMillan & Co., Ltd., London 1935, pp 228-293. Hall Effect for solids and liquids. Also a photoelectric Hall Effect; pp 293-294, Ettingshausen Effect; pp 300-301, Nernst Effect.

Quantities

Current
Magnetic Flux
Temperature
Angle between two quantities
Material
Heat Flow

GAUSS' LAW

I. Description

Gauss' Law states that for a closed surface of any shape constructed in an electric field, the number of lines of force crossing it in an outward direction is equal to $1/\mathcal{E}_o$ times the net positive charge inside the surface. Although this statement is intended to hold only for free space, it may be generalized to include volumes that are partially or wholly occupied by matter. In these cases, the term "net positive charge" should be the algebraic sum of both the free and induced charges enclosed by the surface.

II. Illustration

Gauss' Law greatly simplifies many problems involving the calculation of electric fields. Examples include the calculation of the capacitance in devices having simple geometric shapes, and the calculation of fields about transmission lines. It is also the fundamental relation used in the derivation of many other relations in electricity.

III. Magnitude

There are two equations commonly employed to express Gauss' Law. One uses the concept of the electric field vector, $\overline{E}$, and the other employs the electric displacement vector, $\overline{D}$. They are:

$$\oint E \cos\phi \, dA = \frac{1}{\mathcal{E}_o} \lessdot q \qquad \text{and} \qquad \oint D \cos\phi \, dA = \lessdot q$$

Where $E \cos\phi$ = the component of electric field intensity normal to the surface, volts/meter.
A = surface area, square meters.
$\mathcal{E}_o$ = the permittivity of free space, 8.85×10^{-12} farad/meter.
D = displacement, coulomb/meter^2
$\lessdot q$ = the net positive charge, coulombs
$D \cos\phi$ = normal component of displacement, coulomb/meter^2

This same law is applicable to magnetic fields:

$$\oint \mu H da = \cos\theta \cdot ds = 4\pi \lessdot m$$

Where: μ = permeability
θ = angle between surface and flux
m = magnetic poles inside surface

IV. References

1. Sears, F. W., Principles of Physics, Addison-Wesley, Cambridge, 1947, Vol. II, p 35, p 181.

2. Boast, W. D., Principles of Electric and Magnetic Fields, Harper & Bros., New York, 1948, p 38.

3. Skilling, H. H., Fundamentals of Electric Waves, John Wiley & Sons, New York, 2nd Edition, 1948, p 39.

Quantities

Electric Field
Area
Charge

GEIGER - NUTTAL RULE

I. Description

This rule deals with the range of alpha particles.

$$\log \lambda = A \log R + B$$

λ = decay constant of radioactive material
R = range of particle (in air usually)
A = a constant, the same for each series of radioactive decay elements
B = a constant
T = half life $\quad T = \frac{0.693}{\lambda}$

II. Illustration

The longest-lived radioactive elements produce lower energy alpha particles than do the short-lived elements.

III. Magnitude

Some examples from the Thorium series illustrate this relation.

Radio element	Range (alpha)	Half Life
Thorium (Th^{232})	2.8 cm	$1.39 \times 10^{+10}$ yr.
Radio Thorium (Th^{228})	3.9	1.9 yr.
Thorium A (P_o^{216})	5.6	0.16 sec.
Thorium C' (P_o^{212})	8.6	3.0×10^{-7} sec.

IV. References

1. Glasstone, Samuel, Sourcebook on Atomic Energy, D. Van Nostrand Co., Inc., New York 1950 pp 155-156. Rule, discussion but no examples.

Quantities

Energy
Velocity, linear
Length

GIBBS THEORY OF EQUILIBRIA (Phase Rule)

I. Description

Phase Rule - Defines conditions of equilibrium as a relationship between the number of phases and the components of a system. A system has only three independently variable factors or degrees of freedom - temperature, pressure, and concentration of the components of the system.

A system consisting of "n" components can exist in n + 2 phases, only when the temperature, pressure and concentration have fixed values; if there are "n" components, in n + 1 phases, equilibrium can exist while one of the factors varies; and if there are only "n" phases, two of the varying factors may be arbitrarily fixed.

$$P + F = C + 2$$
$$F = C + 2 - P$$

P = no. of phases
F = degrees of freedom
C = no. components

II. Illustration

The number of phases of a system are the homogeneous mechanically separable and physically distinct portions of a heterogeneous system. The number of phases capable of existence will vary greatly from system to system. There can never be more than one gas or vapor phase since all gases are miscible. A heterogeneous mixture of solid substances forms as many phases as there are substances present.

III. Reference

1. Zemansky, Mark W., Heat and Thermodynamics, McGraw-Hill Book Co., Inc., New York, 1943 pp 321-372. A very complete discussion of principles and problems. Applies the theory to chemical reactions as well as physical chemistry.

See also: Le Chatelier's Law

Quantities

Pressure
Temperature
Concentration

GLADSTONE & DALE'S LAW

VARIATION OF REFRACTIVE INDEX WITH DENSITY

I. Description

The refractive index of a material changes with a change in the density of the material

$$\frac{n-1}{\rho} = c$$

Where: n = refractive index
ρ = density
c, c' = a constant

Another formula for the same phenomena by Lorentz & Lorentz is:

$$\frac{n^2 - 1}{n^2 + 2} \cdot \frac{1}{\rho} = c'$$

II. Illustration

A change in temperature will alter the density of a material, hence change the index of refraction. Since applied forces also change the density, this effect may be used to determine localized stresses. Either formula works for gases at moderate pressures.

III. Magnitude

Since the density variations for changes in temperature are slight, the magnitude of this effect is small; a similar statement is true for the effect of forces. For temperature a few figures may be given:

	Index of Refraction		
Temperature	Carbon Disulfide	Water	Ether
0°C	1.6442	1.3330	-----
10	1.6346	1.3327	1.3592
20	1.6261	1.3320	1.3545
30	1.6182	1.3309	1.3495
40	1.6103	1.3297	-----
50		1.3280	-----
60		1.3259	-----

For Carbon dioxide, the density change is:

Density	n-1 (λ = 5790 A°)
.11558	.02645
.71235	.1659

Reference

1. Preston, Thomas A., The Theory of Light, MacMillan & Co., Ltd., London 1928, pp 155-163. The law, discussion, and magnitude.

Quantities

Angle, refraction
Color
Density
Index of Refraction
Material
Velocity of Light
Wave Length

GRAHAM'S LAW*

I. Description

A) The quantity of a gas which passes through a porous diaphragm in a given time varies inversely as the square root of the molecular weight of the gas, or its density.

B) The rates at which gases diffuse are not the same for all gases, but are inversely proportional to the square root of their densities. The rate is also proportional to the absolute temperature. This movement of gas need not require a porous diaphragm to be termed diffusion.

C) The osmotic pressure produced by a substance in dilute solution is equal to the pressure which this substance would exert if it alone occupied, in a gaseous state, the volume of the solution. The pressure is independent of the nature of the solvent.

II. Illustration

The common name for this phenomena is osmosis. Gases (as well as liquids) exhibit selective diffusion through suitable partitions or membranes. Partitions may be selected that will allow the smaller but not the larger molecules to pass. Sizable pressures may be built up on the sides near the larger molecules. When this process is used to separate gases, it is termed atmolysis. Diffusion is employed in some gas refrigerators which use heat to cool the interior.

III. Magnitude of the Effect

Hydrogen will diffuse four times as fast as oxygen. This follows from the kinetic theory from the fact that molecules of various kinds have the same mean kinetic energy, and hence their mean square speeds are inverse ratios of their masses. A 6% sugar solution and water will develop an osmotic pressure of 307.5 cm of mercury.

IV. References

1. Hodgman, Charles D., Handbook of Chemistry and Physics, Chemical Rubber Publishing Co., Cleveland, Ohio 1946, pp 1743-4, Tables of diffusion coefficient and osmotic pressures.

2. Atkinson, E., Translation of Ganot's Physics, William Wood & Co., New York 1910, pp 437-441. A qualitative description with examples.

3. Page, Leigh, Introduction to Theoretical Physics, D. Van Nostrand Co., Inc., New York 1935, pp 348-351. Mathematical treatment of coefficient of diffusion.

See also: Electro-Osmosis, Fick's Law

Quantities

Molecular Weight
Temperature
Concentration
Flow
Gas
Osmosis
Pressure
Solutions
Time

*Some other names applied to this phenomena are: Van't Hoff, Pfeffer, Atmolysis, Diffusion, Osmosis, Dialysis

GROUP DISPLACEMENT LAW

I. Description

The emission of particles by a radioactive element changes its position in the periodic table. The emission of an alpha particle moves the element two places to the left of the parent, the emission of a beta particle moves the resultant one place to the right in the periodic table.

II. Illustration

This effect may be illustrated by the Thorium Series:

Radio element	Symbol	Atomic No.	Radiation	Half Life
Thorium	Th^{232}	90	α	1.39×10^{10} yr.
↓ Mesothorium I	Ra^{228}	88	β	6.7 yr.
↓ Mesothorium II	Ac^{228}	89	β	6.13 hr.
↓ Radiothorium	Th^{228}	90	α	1.90 yr.
↓ Thorium X	Ra^{224}	88	α	3.64 days
↓ Th. Emanation	Rn^{220}	86	α	54.5 sec.
↓ Thorium A	Po^{216}	84	α	0.16 sec.
↓ Thorium B ↓0.014% Astatine-216	Pb^{212} At^{216}	82 85	$\beta + \alpha$ α	10.6 hr. 3×10^{4} sec.
↓ Thorium C	Bi^{212}	83	$\beta + \alpha$	60.5 min.
↓66.3% Thorium C'	Po^{212}	84	α	3×10^{-7} sec.
Thorium C"	Tl^{202}	81	β	3.1 min.
↓ Thorium D (End Product)	Pb^{208}	82	Stable	-----

IV. Reference

1. Glasstone, Samuel, Sourcebook on Atomic Energy, D. Van Nostrand Co., Inc., New York, 1950 pp 176-179. Law, examples.

Quantities

Atomic Weight
Charge
Energy
Radiation
Time
X-rays

Chemistry
Fluid Mechanics

HENRY'S LAW

I. Description

The quantity of a gas (either weight or volume at N.T.P.) dissolved by a given volume of a given liquid at a given temperature is directly proportional to the pressure under which the absorption takes place.

The quantity of gas which a liquid can dissolve is independent of the nature and of the quantity of other gases which it may already hold in solution.

II. Illustration

The law holds quite exactly for gases of moderate solubility which do not chemically combine with the water as ammonia or hydrogen chloride. The solution of gases in water is usually exothermic.

III. Magnitude

The amount of gas which may be absorbed is proportional to the temperature of the fluid. One c.c. of water at 0°C will hold .0489 cc oxygen at 1 atm pressure, but at 25°C will absorb only .0285 cc. Similar figures for 99.7% pure ethyl alcohol absorbed are 0.2337 and .2171 cc showing that the effect varies from solute to solute.

IV. References

1. MacDougall, Frank H., Physical Chemistry, The Macmillan Co., New York 1936, pp 341-346. Law with examples.

Quantities

Gas
Weight
Volume
Solutions
Pressure
Temperature

Atomic Physics
Electricity & Magnetism
Optics

HERTZ EFFECT (WIEDEMANN AND EBERT) -1887

I. Description

A) Hertz found that a disruptive discharge between two conductors is facilitated by exposing the air space across which the discharge takes place, to the influence of ultra-violet light. Wiedemann and Ebert proved that the seat of this action is at the cathode and that the light produces no effect when the cathode is shielded from its influence, however brightly the rest of the line of discharge may be illuminated. The magnitude of the effect depends on the gas surrounding the cathode. This is also known as the Ebert Effect.

B) Certain substances, when negatively charged, lose their charge when illuminated with ultra-violet light, and that if originally uncharged, they acquire a positive charge as a result of the illumination. The more electro-positive the metal in the contact potential series, the longer the wave length to which it will respond photoelectrically. This is also known as the Elster and Geitel Effect.

II. Magnitude of the Effect

This effect was the first in a long chain of discoveries that have led to the present day photoelectric theory. See this later effect for order of magnitude.

III. Reference

1. Richtmyer, F. K. and E. H. Kennard, Introduction to Modern Physics, McGraw-Hill Book Co., Inc., New York, 1947, pp 70-71. Original experiment and several subsequent ones.

Quantities

Light, visible
Light, ultra-violet
Charge
Radiation

HOOKE'S LAW (1678)

I. Description

As long as the strain is kept below a certain limit for each material, called the elastic limit, the stress is proportional to the strain, and hence, the ratio of stress to the strain (i.e., the elasticity) is a constant:

$$\frac{F}{x} = K$$

where: F = force per unit area (stress)
x = deformation per unit length (strain)
K = Young's Modulus

The elastic limit is the limit stress within which no permanent deformation occurs.

II. Illustration

This law is the basis of spring type scales, the deflection of the spring being proportional to the weight applied.

III. Magnitude of the Effect

Most wrought materials follow this law closely. Other materials such as wood also follow the law well.

Exceptions to the law include concrete, copper, cast iron, etc., which have proportional limits below the elastic limit.

	Yield Strength psi	Young's Modulus psi
Brass	25,000	13,000,000
Beryllium	60,000	19,000,000
Steel (carbon SAE 1040)	50,000	30,000,000

For steel there will be a decrease in length of 1 part in 30,000,000 for one psi.

IV. References

1. Maleev, V. L., Machine Design, International Textbook Co., Scranton, Pa., 1946, Chapter 3.

2. Faires, V. M., Design of Machine Elements, The Macmillan Co., New York, 1946, Chapter 1.

3. Hodgman, Charles D., Handbook of Chemistry & Physics, Chemical Rubber Publishing Co., Cleveland, Ohio, 1946 pp 1703-1708. Elastic constants for solids.

See also: Elastic Limit

Quantities

Force
Area
Length
Strain & Stress

IDEAL GAS LAWS

I. Description

There are a number of related laws regarding an ideal gas behavior.

Avogadro's Law - Equal volumes of all gases at the same temperature and pressure contain the same number of molecules, which for a mole of gas at standard pressure and temperature is 6.023×10^{23}.

For the following laws, the nomenclature to be used is:

P = pressure
T = temperature (absolute)
W = weight of the gas
R = the gas constant
C = A constant
V = volume

Any consistent system of units may be employed.

Boyle's Law (also Mariotti's Law) - If the temperature is constant, the volume of a given quantity of gas varies inversely as the pressure upon it.

$$PV = C_1$$

This equation is approximately true for actual gases and there it works best for low and medium pressures.

Charles' Law - If the volume of a given mass of gas is held constant, the pressure is proportional to the absolute temperature.

$$\frac{DP}{DT} = C_2$$

The change in volume of the container (expansion) must usually be considered

Gay Lussac's Law - This law is very similar to Charles' Law.

$$V_1 = V_o (1 + a \Delta T)$$

V_o = original volume of gas
V_1 = volume of gas at any temp.
ΔT = temperature difference for V_o & V_1
a = constant
air a = .0036706
hydrogen a = .0036613
(both about 1/273)

Ideal Gas Law - By combining the laws of Charles and Boyle, the ideal gas law may be derived:

$$PV = WRT$$

Real gases closely approximate an ideal gas as long as pressures and temperatures are not excessive so that condensation does not occur, since in an ideal gas the molecules do not attract each other. For extreme conditions see Van der Waal's equation. The law applies to mixtures of gases which do not react chemically. See Dalton's Law. Some critical temperatures (see State and Change of State) which limit this law are:

	°C
Steam	374
Sulphur Dioxide	157
Ammonia	132
Carbon Dioxide	31

Dalton's Law of Partial Pressures - In a mixture of gases, each gas exerts the same pressure that it would if it were present alone in the volume occupied by the mixture. That is, for a mixture of gases, the total pressure is the sum of the partial pressures. This law holds true only when the ideal gas laws are valid.

Van der Waal's Equation - This equation considers that the molecules in a gas attract each other, hence is more useful than the ideal gas law.

$$\left(P + \frac{a}{V^2}\right)(V - b) = RT$$

Where: a = constant, effect of molecular attraction
b = constant, effect of volume of molecules

II. References

1. Mac Dougall, Frank H., Physical Chemistry, The Macmillan Co., New York 1936, pp 16-17 Avogadro's number, pp 60-68 Van der Waal's equation and ideal gas law derivation.

2. Page, Leigh, Introduction to Theoretical Physics, D. Van Nostrand Co., Inc., New York 1935, pp 301-4, 331-353. A mathematical treatment of the properties of ideal gases, pp 309-311 Mathematical treatment of Van der Waal's equation.

3. Hodgman, Charles D. (Editor), Handbook of Chemistry and Physics, Chemical Rubber Publishing Co., Cleveland, Ohio 1946, pp 1810-1811. Constants for Van der Waal's equation.

Quantities

Pressure
Pressure, partial
Gas
Temperature
Volume
Weight

IMPEDANCE / FREQUENCY

I. Description

The impedance of a circuit is its total resistance to the flow of an electric current and this impedance for a circuit containing either inductance or capacitance varies with frequency. The magnitude of the impedance of a pure inductance is directly proportional to the frequency of the voltage imposed upon it.

$$Z = j\omega L$$

L = inductance in henrys
= frequency in radians per second
Z = impedance in ohms
J = $\sqrt{-1}$

The impedance of a pure capacitive element is inversely proportional to frequency of the imposed voltage.

$$Z = -j\frac{1}{\omega C}$$

C = capacitance in farads

When using capacitance and inductance together it is possible to create circuits with either very high or very low impedance at a desired frequency.

II. Illustration

By holding the voltage constant across either an inductance or a capacitance, the current through the impedance would be a measure of electrical frequency.

The combination of a capacitator and an inductance in a series or a parallel resonance circuit resonates at a frequency determined by their value.

$$\omega = \left(\frac{1}{LC}\right)^{\frac{1}{2}}$$ (If the resistance is small).

III. Magnitude of the Effect

The magnitude of inductive impedance is proportional to the frequency. For an inductance of one henry and a frequency of one radian/second the impedance is one ohm.

The magnitude of capacitive impedance is inversely proportional to frequency. For a capacitance of one microfarad and a frequency of one radian/second, the impedance is one megohm.

IV. Reference

1. Hehre, Fredrick W. and George T. Harness, Electrical Circuits and Machinery, Volume II, Alternating Current, John Wiley and Sons, Inc., New York, N.Y., 1942. pp 26-30 Inductance in d.c. and a.c. circuits. pp 31-38 Capacitors, construction and effects in d.c. and a.c. circuits.

Quantities

Inductance
Capacity
Frequency
Impedance

INTERFERENCE

I. Description

For light, interference produces a number of colored or dark bands depending on whether white or monochromatic light is used. These result from interference between two light sources a short distance apart, or the same light traveling through two slightly different path lengths. In sound, this phenomena is termed beats, but is then caused by excitation of two slightly different frequencies.

II. Illustration

Two mirrors side by side, but not quite in the same plane were used by Fresnel to produce these fringes. Two glass plates at slight angles to each other may also be used. Grazing incidence of light on a mirror is another means of producing fringes. Thin films also illustrate the interference of light (Newton's Rings) because of the difference in path length from the upper and lower surfaces of the film for reflections. Interference films are sometimes placed on mirrors so that only a selected bandwidth is reflected. Beats are used in musical chords to produce pleasing tones.

III. Magnitude

In order that the interference patterns of light may be visible, the path lengths must not be different by more than a few wave lengths. Because of this small allowable deviation, the fringes may be used to determine the flatness of a surface to a few millionths of an inch.

Thin films are produced on tantalum foils oxidized in the process of making electrolytic capacitors, the film color being a rather direct indication of the D.C. formation voltage and formation temperature.

IV. References

1. Preston, Thomas A., The Theory of Light, MacMillan & Co., Ltd., London, 1928, pp 164-241. History and discussion of many ways to produce interference bands for light.

2. Sugg, Ronald E., An Interferometer for Examining Polished Surfaces, Mechanical Engineering, Vol. 75, No. 8, August 1953, pp 629-631. Industrial use of interferometer.

3. Sugg, R. E., Micro Interferometry for Surface Measurements, Product Engineering, Vol. 23, No. 8, pp 156-157. Interference applied to measuring a very flat surface.

See also: Diffraction.

Quantities

Length
Thickness
Wave Length
Sound
Light, visible

JOHNSEN-RAHBEK and/or WINSLOW EFFECT

I. Description

It has been found that when two conductors are separated by a semi-conductor and a voltage is applied to the conductors the friction between the conductors and the semi-conductor increases. When the semi-conductor is a solid the effect is called the Johnsen-Rahbek Effect and when the semi-conductor is a liquid the effect is called the Winslow Effect. This configuration is a capacitor and there is an attractive force between the electrodes. Naturally this force increases the friction force parallel to the face of the electrode but in actual practice the frictional force increases faster than the attractive force so that there must be some effects of voltage other than just the increase of attractive force. Theory indicates that the application of a voltage across a semi-conducting fluid causes particles (such as finely divided materials, molecules, etc.) to form conducting chains thus increasing the viscosity of the liquid. Hence it is seen that this phenomenon is quite similar to the magnetic fluid coupling although the effect is not as strong because the attractive properties of the particles are less. Similar reasoning may be applied to the solid semi-conductor unit because the semi-conductor may be saturated with an electrolyte which could act as the fluid. For a small air gap the air could form conducting chains. The effect is also present with dry semi-conductors.

II. Illustrations

Materials that have been used:

Conductors: Any good conductor that can be given a smooth flat surface

Semi-conductors:

Solid:
- Agate
- Lithographic stone
- Sintered magnesium oxide and titanium dioxide

Liquid:
- Pyranol
- Inerteen
- Mineral oil and lanolin

Applications of the fluid type semi-conductors are quite well covered in U.S. Patent 2,417,850 of April 14, 1942.

The device may be used similar to a magnetic fluid type clutch. The unit will require less power as the effect depends on voltage and not current but its torque capacity is considerably less than a magnetic type clutch.

One of the more promising applications of this effect is a voltage operated low torque relay.

This effect has been applied to loud speakers where the audio signal is used to change the friction between a spring loaded ribbon attached to the loud speaker diaphragm and an agate cylinder rotating at constant speed.

III. Magnitude of the Effect

The magnitudes of this effect are hard to determine as most of the work done so far has been experimental and not analytical. Also there has been a wide variation in materials used which gave different magnitudes.

One experiment showed that the friction force between a rotating agate cylinder and a strip of tinfoil in contact with 180 degrees of the cylinder surface varied as the fifth power of the voltage between 25 and 300 volts.

The order of magnitude of this force is grams not pounds.

IV. References

1. Science Abstracts "A" 1934 (Vol. XXXVII). Engineers Book Shop, N.Y., Item 3909. Also Vol. A 1928 item #3099. Abstracts & formulae from foreign papers.
2. Journal of Applied Physics, May, 1950, pp 402-413. The effect for liquids.
3. Johnson, Alfred and Knud Rahbek, A Physical Phenomena and its Application to Telegraphy, Telephony, etc., The Journal of the Institution of Electrical Engineers, Vol. 61, 1923. Span & Chamberlain, N. Y., pp 713-725. Qualitative description and uses. Mentions electromatographic effect.

Quantities

Friction	Force
Material	Voltage

JOULE'S LAW

I. Description

The heat produced by the passage of an electric current through a solid metallic conductor is proportional to the resistance of the conductor, the square of the current and the time, or to the product of the applied e.m.f., the current and the time.

$$JH = RI^2t = EIt$$

Where J is Joule's dynamic equivalent of heat, H the number of units of heat, R the resistance of the conductor, I the current, t the time during which the current flows and E the applied e.m.f.

II. Illustration

A method of measuring high frequency current is to heat a thermocouple with a series resistance. The temperature differential between thermocouple junctions is a measure of the high frequency current.

III. Magnitude of the Effect

For a circuit having a resistance of one ohm and a current of ten amps the rate of heat generation will be 100 watts. For modifications of this law, see Thompson Effect.

IV. Reference

1. Housmann, Erick and Edgar P. Slack, Physics, D. Van Nostrand Co., Inc., 1939, pp 370-371. Description and examples.

Quantities

Resistance (electrical)
Current
Time
Energy

General Physics
Fluid Mechanics
Chemistry

JOULE-THOMSON EFFECT OR JOULE-KELVIN EFFECT

I. Description

When a gas expands through a throttling device, the temperature of the gas is lowered or raised depending on the temperature at which the process takes place and upon the physical properties of the gas.

The fall in temperature for air by the Joule-Thomson effect is:

$$\text{Fall in Temp.} = \frac{P_1 - P_2}{4} \frac{(289)}{(T_1)}$$

where: P_1 = pressure in atm. before throttling
P_2 = pressure in atm. after throttling
T_1 = temp. before throttling in ^{o}K

There is a molecular force between molecules of a gas. When the gas expands, the molecules become more widely separated. In order for the expansion to go on, the force between the molecules must be overcome, which is an action requiring energy. This energy is derived from the heat energy of the gas itself; so if the gas uses its own heat for expansion, its content of heat is reduced and its temperature is lowered.

At ordinary temperatures, certain gases such as hydrogen, when undergoing the same process will have a heat rise instead of drop. This is due to all gases having what is called an inversion temperature. Below this temperature a gas will cool upon being expanded and above this temperature the gas will gain heat. Hydrogen has a low inversion temperature so its initial temperature has to be reduced below ordinary temperatures (about -183°C) before the Joule-Thomson effect takes place.

II. Illustration

Practical use of the Joule-Thomson effect is used in making liquid air by the Linde process.

III. Magnitude of the Effect

The rate of change of temperature with respect to pressure under the conditions of the Joule-Thomson experiment is called the Joule-Thomson coefficient.

$$\text{J. T. C.} = \frac{(dT)}{(dP)h}$$

where h denotes constant enthalpy.

When a gas is at its inversion temperature the J. T. C. is 0.

IV. References

1. MacDougall, Frank H., Physical Chemistry, The Macmillan Co., New York, 1936. pp 40-42, Primarily a mathematical treatment.

2. Zemansky, Mark W., Heat & Thermodynamics, McGraw-Hill Book Company, Inc., New York 1943. pp 249-258, Effect and some uses.

Quantities

Temperature
Gas
Volume
Pressure

KELVIN'S PRINCIPLE FOR FLUID DROPS

I. Description

The size of liquid drops which may exist in a super saturated vapor depends upon the degree of super saturation.

$$\text{Log}_e \frac{P}{P_s} = \frac{2S}{RT\rho r}$$

P = the pressure of the super saturated vapor
P_s = the normal pressure of saturation on a flat surface
S = the surface tension
R = a constant
T = the absolute temperature
ρ = density of the fluid
r = radius of the drop

For water, if a drop is 10^{-4} mm in diameter, the ratio P over P_s is 1.02, while for a drop diameter of 10^{-6} mm, P to P_s is 10.2.

II. Illustration

The nuclei which must be available to condense super saturated vapors must equal the minimum size drops for these same conditions.

III. References

1. Ewing, J. A., Thermodynamics, Cambridge University Press, 1946, pp 343-346. A mathematical discussion.

Quantities

Diameter
Density
Equilibrium
Radius
Surface Tension
Temperature
Vapor Pressure

KEPLER'S LAWS

I. Description

Free Elliptic Motion

A) The planets move about the sun in ellipses, the sun at one focus.

B) The radius vector joining a planet with the sun describes equal areas during equal times.

C) The cubes of the mean distances of the planets from the sun are proportional to the squares of their times of revolution about the sun.

These laws can be generalized to include all free-body revolutions about an attracting point if the force of attraction is inversely proportional to the intervening distance.

The generalized laws are:

A) The point toward which the acceleration is directed is at one of the two foci of the path ellipse.

B) A radius-vector drawn from that point to the moving body sweeps over equal areas in equal times as the body moves.

C) The time taken to perform a complete revolution in the elliptical path is proportional to the square root of the cube of the mean distance from the central point.

II. Illustration

This law can be applied to the calculation of the orbits of submicroscopic particles as well as astronomical bodies.

The conservation of moment of momentum theorem known otherwise as the Law of Areas states that the magnitude of the momentum is equal to the product of the mass and twice the area swept over in unit time by a radius vector when the only forces acting on it are central forces, that is, forces not producing torques. Applied to planets around the sun this is Kepler's First Law.

III. References

1. Karman & Biot, Mathematical Methods in Engineering, McGraw-Hill Book Co., Inc., New York 1940, page 77.

2. Page, Leigh, Introduction to Theoretical Physics, D. Van Nostrand Co., Inc., New York 1935, pp 88-97. Mathematics of motion under inverse square form of attraction.

Quantities

Acceleration
Area
Force
Time
Length
Motion

KERR EFFECT (ELECTROSTATIC)

I. Description

Certain substances which normally are optically insotropic become double refracting when subjected to an electric field.* (The index of refraction for light whose electric vector is parallel to the applied field is different from light whose electric vector is perpendicular to the applied field). Thus, plane polarized light whose electric vector has components both parallel and perpendicular to the applied electric field will become elliptically polarized when passing through the substance which exhibits the Kerr Effect. The phase difference angle is given by the following equation:

$$\delta = 2\pi K l E^2$$

Where: δ = time phase difference angle (radians) between polarized light components
K = Kerr constant of substance
l = path under influence of electric field (cm)
E = electric field (c.g.s. units)

The Kerr constant of most substances is a function of both temperature and the wave length of the transmitted light.

II. Illustration

The Kerr Effect may be used as an optical shutter. This is accomplished by placing a polarizer before the Kerr cell that is oriented so that the electric vector of the light is at an angle of 45° (for best results) with the electric field. An analyzer is placed behind the Kerr cell and is adjusted for zero light passage when no electric field is applied to the Kerr cell. The shutter is then opened by applying a voltage to the Kerr cell. Modern pulse techniques permit very accurate timing of shutter opening and closing. (5×10^{-9} seconds)

III. Magnitude of the Effect

A Kerr cell using nitrobenzene as the fluid in a unit 2 cm. long and having a spacing between plates of 0.5 cm. will require approximately 15,000 volts (MKS units) to fully open the shutter. This will pass one fourth of the incident non-polarized light.

Substance	Kerr Constant	Resistivity (Ohms-Cm.)	Dielectric Constant
Carbon disulphide CS_2	3.6×10^{-7}	10^{16}	2.5
Chloroform $CHCl_3$	-3.2×10^{-7}	10^{8}	5.0
Aceton C_3H_6O	16×10^{-7}	10^{7}	20.0
Nitrobenzene $C_6H_5NO_2$	400×10^{-7}	10^{10}	36.0

Time lag for nitrobenzene is less than 10^{-9} seconds. Some glasses have time lags as high as 30 seconds.

IV. Reference

1. Porter, Alfred Co., The Theory of Light, MacMillan & Co., Ltd., London, 1928, pp 466-468. Qualitative description.

*Note: Cotton and Mouton observed this same effect with a magnetic field in 1905.

Quantities

Polarization
Electric Field
Light, visible
Material
Time

KERR MAGNETO-OPTIC EFFECT

I. Description

When plane polarized light is incident on the pole of an electro-magnet, polished so as to act like a mirror, the plane of polarization of the reflected light is not the same when the magnet is "on" as when it is "off". It is found that the direction of rotation depends upon the direction of light polarization and the angle of incidence. The rotation from the non-magnetized plane will be proportional to the flux density leaving the polished metallic surface.

This effect can be used to detect the strength of magnetic flux density, type of material and frequency of incident light.

II. Illustration

This effect can be used to measure the intensity of magnetic flux leaving a magnetic pole. The degree of rotation of the plane of polarization will be the true indication of the flux density. This rotation may be used to examine thin surface films, since the reflection and the rotation is a surface phenomena.

III. Magnitude of the Effect

Fe = 0.014'/gauss)
Co = 0.015'/gauss) = 5300 Angstrom Units
Ni = 0.016'/gauss)

IV. References

1. Wood, Physical Optics, Macmillan & Company, New York, page 401

2. Bhatmayer, S. S. and K. N. Mathur, Physical Principles and Applications of Magneto-chemistry, MacMillan & Co., Ltd., London 1935, pp 278-279. Various conditions and results.

Quantities

Magnetic Flux
Color
Light, visible
Material
Polarization

KIRCHHOFF'S LAWS

I. Description

1. At any point in a circuit there is as much current flowing away from the point as there is flowing to it.

2. The sum of the several IR drops around any one path of an electric circuit equals the sum of the EMF's impressed on the same path.

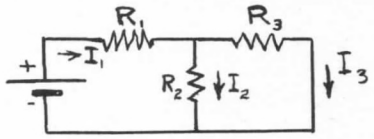
II. Illustration

For the first law

$I = I_a + I_b + I_c$

Otherwise there would be a charge build-up at the junction X.

The second law



$I_1 = I_2 + I_3$ (by the first law)

$E = I_1R_1 + I_2R_2 = I_1R_1 + I_3R_3$

$0 = I_2R_2 - I_3R_3$

(The negative sign occurs because direction of travel in the loop is opposite to that of the current)

It should be noted that Kirchhoff's laws apply to instantaneous values, and for circuit (not field) problems. The law is not in general true for r.m.s. a.c. values, because of the phase angles encountered.

III. Reference

1. Timbie, William H. and Vannevar Bush, Principles of Electrical Engineering, John Wiley and Sons, Inc., N. Y., 1940. Chapter II (pp 28-46)

Quantities

Current
Voltage

KOHLRAUSCH'S LAW*

I. Description

The limiting equivalent conductance of an electrolyte is due to the sum of two migrations: that of the cations and that of the anions. These two types of ions migrate independently to produce conduction.

The equivalent conductance of strong electrolytes in extremely dilute solutions is a linear function of the square root of the concentration.

The equivalent conductance of an electrolyte is the conductance of a column 1 cm long and containing 1 mole of solute. The conductive approaches a limiting value as the concentration of the dissolved solute approaches zero.

II. Illustration

The law may be expressed as:

$$\Lambda = \Lambda_0 - A C^{\frac{1}{2}}$$

Where: Λ = equivalent conductance
Λ_0 = limiting equivalent conductance
A = constant, depending on electrolyte and temperature
C = concentration in moles/liter

A, as determined by Onsager is:

$$A = \left[\left(\frac{5.78 \times 10^5 \Lambda_0}{(D\,T)^{3/2}} \right) + \frac{58.0}{(D\,T)^{\frac{1}{2}} \eta} \right] \sqrt{2}$$

D = dielectric constant of the solvent (free space = 1)
T = absolute temperature
η = viscosity

III. Magnitude

For HCl, the conductances for concentrations up to .0016 moles/liter are found to within 0.05%. The expression holds poorly, however, for low concentrations of the weak electrolytes.

IV. References

1. Mac Dougall, Frank H., Physical Chemistry, The Macmillan Co., New York 1936, pp 471-477. Discussion with examples.

2. Dale, Malcolm, Principles of Experimental and Theoretical Electro-Chemistry, McGraw-Hill Book Co., Inc., New York, 1934, pp 89-106. Debye- Huckel equations, Onsager's conductance theory and other for concentrated solutions.

See also: Wien Effect

Quantities

Concentration
Current
Dielectric Constant
Material
Resistance, electrical
Solutions
Temperature

*Also known as Debye-Huckel Equation or Onsager's Conductance Theory.

LAMBERT'S LAW, ABSORPTION COEFFICIENT

I. Description

Radiation, including light, which has transversed any thin layer of matter perpendicular to the direction of propagation is reduced in intensity in proportion to the thickness of the layer. The flux density after having penetrated the medium to a distance "x" is:

$$I = I_0 C^{-ax}$$

in which I_0 is the flux density upon entrance into the medium (i.e. $x = 0$). For true absorption the constant "a" is the absorption coefficient. The law holds when scattering does not occur.

Beer's Law, which is an extension of Lambert's Law, states that if two solutions of the same salt be made in the same solvent, the first of which is twice the concentration of the other, the absorption due to a given thickness of the first solution should be equal to that of twice the thickness of the second.

II. Illustration

The absorption coefficient of copper for certain x-rays is 13.5 cm^{-1}, the radiation in passing through 0.0513 cm. will emerge only one-half as intense. The effect is also of importance with thick windows as used for shielding against radioactive materials and in other test cells.

Failure of Beer's Law to hold is due to a reaction between the solvent and solute or a change in the molecular state of the solute with changes in its concentration; i.e., "packing" of the molecules.

III. Magnitude of the Effect

In general the absorption coefficient of a medium varies characteristically with the wave length of the radiation, as illustrated by the absorption of x-rays in aluminum.

Wave Length	Absorption Coefficient (cm^{-1})
100×10^{-11} cm	0.45
200	0.72
300	1.45
400	2.95
500	5.30
1000	38.00

IV. References

1. Hodgman, C. D., Handbook of Chemistry & Physics, Chemical Rubber Publishing Co., Cleveland, 1946, pp 2005-2010. Tables of coefficients.

2. Koller, Lewis R., Ultraviolet Radiation, John Wiley & Sons, Inc., New York, 1952, pp 140-177. Law, examples, and materials.

3. Walsh, John W. T., Photometry, D. Van Nostrand Co., New York, 1926, pp 116 and 246.

Quantities

Energy
Light, visible
Radiation
Thickness
X-rays
Solutions
Material

LE CHATELIER'S LAW

I. Description

If some stress (e.g. change of temperature, pressure or concentration) is brought to bear on a system in equilibrium, the equilibrium is displaced in the direction which tends to undo the effect of the stress.

This applies to all systems and changes of the condition of equilibrium, whether physical or chemical. Other names are Law of Mass Action and Principle of Le Chatelier-Braun.

Chemically this law is known as Van't Hoff's Principle and states that if the temperature of interacting substances in equilibrium is raised, the equilibrium concentrations of the reaction are changed so that the products of that reaction which absorb heat are increased in quantity, or if the temperature for such an equilibrium is lowered, the products which evolve heat in their formation are increased in amounts.

II. Illustration

Thus when a system in equilibrium is subjected to an increase in pressure, it adjusts itself so that it will occupy less volume. This will offset the pressure increase.

If ice is placed under an increased pressure, it melts because the water obtained from a given mass of it occupies less volume. (Regelation)

III. Magnitude

For a physical system the Clapeyron-Clausius equation gives the relation of change in state to temperature and pressure:

$$l = T\left(\frac{dp}{dT}\right)\Delta V$$

Where l = heat for change of state
ΔV = change in volume for change in state
T = temperature
dp = change in pressure

IV. References

1. Mac Dougall, Frank H., Physical Chemistry, The Macmillan Co., Inc., New York, 1936. pp 295-296. Law of Mass Action. pp 325-336, Le Chatelier's Law and examples.

2. Dole, Malcolm, Principles of Experimental and Theoretical Electro-Chemistry, McGraw-Hill Book Co., Inc., New York, 1935. pp 322-350. Law of Mass Action, mainly concerned with dissociation.

3. Taylor, Hugh S., A Treatise on Physical Chemistry, Volume I. D. Van Nostrand Co., New York, 1924. pp 307-468. Chemical and Physical equilibria, with examples.

Quantities

Concentration
Equilibrium
Pressure
Temperature

MAGNETIC BEHAVIOR OF MATERIALS

I. Description

If a magnetizing force is applied to a material, the ratio between the number of flux lines resulting in the material as compared with those which would result in free space is defined as the permeability of the material or μ. The value of μ defines the material:

Ferromagnetic - Strongly attracted to a magnet; $\mu \gg 1$ (may be 10^6). These materials which also have a high residual magnetism are termed permanent magnets. Temperatures near absolute zero may alter the magnetic properties of the material. Examples, iron, nickel, cobalt. (See Curie-Weiss Law)

Paramagnetic - Slightly attracted to a magnet; $\mu > 1$. In general these materials have quite temperature sensitive behavior. Examples are oxygen and nitric oxide. This effect is small compared to ferromagnetic forces.

Diamagnetic - Repelled from the magnet; $\mu < 1$. Bismuth is an example, some types of glass are other examples. This effect produces small forces.

II. Illustration

The paramagnetic properties of oxygen are used in a continuously indicating meter to measure the per cent oxygen in the gas mixture. The magnetic properties of materials have been used to analyze their substance.

III. References

1. Zemansky, Mark W., Heat and Thermodynamics, McGraw-Hill Book Co., Inc., New York, 1943, pp 271-279. Paramagnetic materials and use of adiabatic demagnetization.

2. Permanent Magnet Design Manual, Carboloy Publication, No. PM-101

3. Bhatnager, S. S. and K. N. Mathur, Physical Principles of Applications of Magneto-chemistry, MacMillan & Co., Ltd., London, 1935. Sections of the book will be found useful for any phase of this subject.

See also: Faraday Magneto-Optic Effect
Cotton-Mouton Effect
Kerr Effect
Zeeman Effect

Quantities

Magnetic Flux
Material

Electricity & Magnetism
Acoustics
Mechanics

MAGNETIC DISPERSION OF SOUND

I. Description

Sound waves traveling in an electrically conducting plate perpendicular to a magnetic field will generate a voltage so as to reduce (Lenz's Law) the longitudinal movement of the metal. This effect has two aspects: the phase velocity of the wave is increased, and the mechanical stiffness of the material is increased.

II. Illustration

This voltage is masked in ferro-magnetic materials by the Villan Effect. The formula for change in phase velocity is:

$$c/c_o = 1 + \frac{40.1\, d\, B_o^2 \sigma^{\frac{1}{2}}}{\rho \mu_r^{\frac{1}{2}} h\, f^{3/2}}$$

Where:
- c = phase velocity of sound with field
- c_o = phase velocity of sound
- d = $1-e^{-sh}$ (Cos sh + sin sh)
- B_o = magnetic field intensity (Weber/m^2)
- σ = conductivity
- ρ = density
- μ_r = relative permeability
- h = thickness of the bar
- f = frequency in cps
- s = $\frac{1}{\delta}$
- δ = skin depth

Material	$\sigma^{\frac{1}{2}}/\rho\mu_r^{\frac{1}{2}}$
Lithium	0.064
Calcium	0.030
Magnesium	0.028
Aluminum	0.022
Chromium	0.009
Copper	0.0085
Silver	0.0075
Iron	0.00034

III. Magnitude

As shown in the table, the effect is maximum for lithium. The phenomena has been observed in magnesium, aluminum and copper. A magnesium alloy bar with a resonant frequency of 16.914 kc had the frequency increased by 0.238 kc upon the application of a magnetic field of 1.0 Weber/m^2.

IV. Reference

1. Robey, Donald H., Magnetic Dispersion of Sound in Electrically Conducting Plates, The Journal of the Accustical Society of America, Vol. 25, No. 4, July 1953, pp 603-609

Quantities

Current
Density
Frequency
Material
Motion
Permeability
Resistance, electrical
Thickness
Velocity of Sound
Vibration
Sound

MAGNETIC EFFECTS

I. Description

This is a summary of a number of magnetic effects.

A. Mechanical effects caused by a magnetic field: (on material in field)

1. Joule Effect* -- change in length due to a longitudinal field-small magnitude, sensitive to temp. and pressure, greatest for nickel (see Magnetostriction).
2. Transverse Joule Effect -- change in transverse dimensions.
3. Change in Young's modulus.
4. Guillemin Effect -- bending due to a field.
5. Wiedemann Effect* -- twist caused by circular and longitudinal fields.
6. Change in coefficient of rigidity (See Magnetic Dispersion of Sound).
7. Barrett Effect - change in volume.
8. Gyro-magnetic effect - the recoil experienced by ferromagnetic and paramagnetic coils because of the angular momentum of the electrons in the substance.

B. Magnetic effects caused by mechanical stresses:

1. Villari Effect* -- change in induction due to stresses parallel to field; for weak fields flux is increased; for strong fields, reduced.
2. Transverse Villari Effect -- change in induction because of transverse stresses.
3. Werthiem Effect* -- circular magnetization caused by twisting a longitudinally magnetized bar.
4. Nagaoka - Honda Effect -- change in intensity of magnetization due to volume changes.

II. Miscellaneous

1. Discharge tubes (electrical) -- a magnetic field will change the current through the tube.
2. Flame -- a magnetic field tends to increase flame resistance and in some cases affect its brightness.
3. Fluorescent gases -- a magnetic field tends to decrease the intensity of the fluorescence.
4. Chemical reactions -- some accelerated, others not, no general conclusions.
5. Optics -- magnetic fields of a few hundred gauss applied to nematic type liquid crystals clears up the opacity of the liquid.

*See page by this name for details.

III. Reference

1. Bhatnazer, S. S., and K. H. Mathur, Physical Principles and Applications of Magnetochemistry, MacMillan & Co., Ltd., London, 1935, pp 233-288, Short discussions of several of the above effects. pp 299-300, Miscellaneous effects; pp 326-335, Chemical reactions.

Quantities

Length
Motion
Permeability
Magnetic Flux

MAGNETIC SUSCEPTANCE (GAUSS EFFECT)

I. Description

The resistance of iron and nickel increases if magnetized in the same direction as the current flow, and decreases if the magnetic field is transverse. The effect is proportional to the square of the field intensity.

Bismuth is one of the few metals which shows a usable magnetic susceptance or Gauss effect. This effect is shown by placing a strip of wire in a magnetic field and measuring the change in electrical resistance for different field intensities. This linear change of resistance with field strength (above 2000 Gauss) for bismuth is diminished at low field values by the effect of temperature. This material also has a large Hall effect and is the most diamagnetic material known.

II. Illustration

Bismuth wire coils have been used to explore variations in flux intensity for space as well as time coordinates.

III. Magnitude

For bismuth wire, resistance values are:

H (Gauss	°C→ -192°	-37°	0°	18°	60°	100°
0	.40	.88	1.00	1.08	1.25	1.42
4,000	2.32	1.10	1.18	1.21	1.31	1.46
6,000	4.00	1.24	1.30	1.32	1.39	1.51
10,000	8.60	1.72	1.57	1.54	1.54	1.62
20,000	19.8	2.81	2.38	2.20	1.97	1.95
35,000	35.5	4.95	3.62	3.25	2.69	2.95

IV. References

1. Bozorth Ferromagnetism, D. Van Nostrand Co., Inc., New York, p 745

2. Bhatmager, S. S. and K. N. Mathur, Physical Principles & Applications of Magneto-chemistry, MacMillan & Co., Ltd., London, 1935, pp 294-299. Discussion for solids and liquids.

3. Campbell, L. L., Galvanomagnetic & Thermomagnetic Effects, Longman's Green and Co., N.Y., 1923, pp 158-208. Various materials and effect of field.

Quantities

Magnetic Flux
Resistance, electrical
Temperature

MAGNETOSTRICTION AND ALLIED EFFECTS

(Joule, Villari, Wertheim and Wiedemann Effects)

I. Description

The term "Magnetostriction" refers to the change in dimensions of a ferromagnetic material when it is placed in a magnetic field. It also applies to the inverse effect; that is, the change in magnetization when the dimensions are changed by an external force.

Magnetostriction is exhibited by the ferromagnetic metals, iron, nickel and cobalt and most alloys of these three. The lesser known ferromagnetic "Heusler Alloys" (containing copper, manganese, and tin originally) and gadolinium also are magnetostrictive.

Magnetostriction effects are classified as follows:

A. Joule Effect

The Joule Effect deals with the change in length of a ferromagnetic material along the axis of the applied magnetic field, when this field is changed. For most purposes the longitudinal change is important, but it should be noted that a volume and transverse change also occurs. The volume change is the basis of the low expansion alloys to be described later.

B. Villari Effect

The Villari Effect relates to the fact the magnetization of a material, in the presence of a field, is altered upon the application of external stress.

C. Villari Reversal

In pure iron, under conditions of high field strength, the magnetostriction effect changes sign, i.e. the direction of dimensional change reverses.

D. Wertheim Effect

When a wire, placed in a longitudinal magnetic field is being twisted, there is a transient voltage difference between the ends of the wire.

E. Wiedemann Effect

The direct Wiedemann effect is the twist produced in a wire, placed in a longitudinal magnetic field, when a current flows through the wire. This is due to the helical resultant of the impressed longitudinal field and the circular field of the wire. The magnetic material expands (or contracts) parallel to the helical lines of force and hence the twist. The inverse Wiedemann effect is the axial magnetization of a current carrying wire, when twisted.

E. Allied Effects

1. Change in electrical resistance due to field. (Gauss Effect)
2. Change in thermoelectric emf due to field. (Nernst Effect)
3. Emf due to magnetization. (Faraday's Law of induction)
4. Change in frequency of tuning fork due to a field.
5. Sounds produced by magnetization.

Factors that control the effects:

1. Heat treatment
2. Stress
3. Hardness
4. Impurities
5. Previous magnetic history

II. Illustration

As recently as 1926, it was said that no important use had been made of magnetostriction or effects closely related. Since that time it has developed from a laboratory curiosity to an item of commercial manufacture. The following list will give some idea of the diverse fields it has entered.

II. Illustration (Cont)

1. "Sonar" and related devices for detecting submarines and ships.
2. The "Fathometer" used to determine the depth of uncharted waters. Post war use of this device has been to locate schools of fish.
3. Electrical filters, in particular, a band pass filter for use in commercial receiving sets.
4. Homogenization and sterilization of milk.
5. Acceleration of chemical reactions and cavitation effects. Ultrasonic soldering iron.
6. Strain gages.
7. Vibration and engine detonation.
8. Phonograph pickups.
9. Frequency control of oscillators operating below 100,000 cycles.
10. Dust precipitation.

III. Magnitude of the Effect

At this point it would be well to dispel two popular misconceptions concerning magnetostriction. The first is that large changes in length take place. Actually, in nickel, which shows one of the largest changes per unit length of all the materials investigated, this amounts to about 30 parts in one million. For a nickel rod one foot long, this would amount to 3.6 ten thousandths of an inch. At resonance this change may be as high as one part in a thousand (limited by fatigue properties) or a rod one foot long changes about one hundredth of an inch. The other popular misconception is that a rod, constrained at each end and subjected to a magnetic field will exert an infinite force in attempting to contract. Actually, the static force is determined by change in length and the modulus of elasticity of the metal. For nickel the maximum static force is about 1000 p.s.i., while the force for iron or cobalt is lower.

A) Joule Effect

The Joule Effect can be determined within an accuracy of 4 to 5% with iron.

$\frac{l - l_o}{l_o} = -7.53 \times 10^{-6}$ H = 1800 gauss, Iron-carbon alloy

$\frac{l - l_o}{l_o} = 64.67 \times 10^{-6}$ H = 550 gauss, Iron-cobalt alloy

B) Wiedemann Effect

The Wiedemann Effect can be determined with higher precision.

1. For a circular cylinder, bar or tube in a longitudinal field of 75 gauss and a current of 8.86 amps the twist was 0.954 seconds of angular deflection per cm of length.
2. For a low carbon steel tube where

$D_o = 0.16$ cm $D_1 = .0794$ cm $l = 79.8$ cm

$H = 30$ gauss $I = 1.5$ amps

The deflection was 5.226 minutes per cm of length.

IV. References

1. Bozorth, R. M., Ferromagnetism, D. Van Nostrand Co., Inc., page 628.

2. Koboyasi, T., On the Inverse Wiedemann Effect and Allied Phenomena, Japanese Journal of Physics Transactions, No. 1, Vol. 5, p. 116 thru 139, and No. 3, Vol. 5, p 111 thru 117.

3. Bradfield, G., A New Electro-Acoustical Transducer, Electronic Engineering, March 1948, Vol. 20 No. 241 pp 74-78. A pulse generator and receiver using magnetostriction.

4. Magnetostriction. A pamphlet published by Development & Research Division, The International Nickel Co., Inc., New York 5, N. Y., February 1952.

Quantities

Force
Frequency
Material
Sound
Magnetic Flux
Length
Displacement, angular

NEWTON'S LAWS

I. Description

A. A body at rest remains at rest, and a body in uniform motion continues in a straight line unless the body is acted upon by an unbalanced force.

B. A body accelerates in proportion to and in the same direction as the unbalanced force acting upon it.

C. For every action, there is an equal and opposite reaction.

II. Illustration

A combination of the first and second laws allows a description of planetary motions. (See Kepler's Law).

The third law is basic to a number of fields. Examples are Lenz's Law, Hooke's Law, Gibbs Theory of Equilibria, and the Peltier Effect.

III. Magnitude

The formula covering these three laws is:

$F = ma$ where $F =$ force (unbalanced on the mass)
$m =$ mass
$a =$ acceleration of the mass

This formula is used to define the units of various systems of measures. Some consistent sets are listed below.

F.	m.	a	
poundal	pound	ft/sec^2	British Absolute
pound	slugs	ft/sec^2	British Gravitational
dyne	gram	cm/sec^2	Metric Absolute
gram	$gram/cm/sec^2$	cm/sec^2	Metric Gravitational

The formula has been modified somewhat by relativistic concepts, but it is still used whenever the velocity of the mass does not exceed 1/10 the speed of light.

D'Alembert's principle uses the third law (and the formula) to allow a force balance in dynamic situations with accelerating particles.

IV. Reference

1. Campbell, J. W., An Introduction to Mechanics, Houghton, Mifflin Company, New York, 1929. pp 24-30. Laws, problems. pp 253-261 D'Alembert's principle, illustrations, problems.

Quantities

Acceleration
Direction
Equilibrium
Force
Mass
Motion

OHMS LAW

I. Description

The current through a resistance will be proportional to the electromotive force across the resistance.

Where: $I = \frac{E}{R}$

I = current
E = EMF of cell
R = resistance of circuit

For alternating currents, R is replaced by $Z = \sqrt{R^2 + \left(wL - \frac{1}{wC}\right)^2}$

Where: Z = impedance (ohms)
w = $2\pi f$
f = frequency in cps
L = inductance in henries
C = capacity in Farads

II. Illustration

Inserting a resistance in series with a current reading meter will change it to a device for indicating voltage. The voltage range being dependent on the current range of the meter, and the value of the series resistance. At high current densities there are slight deviations from the law.

III. Magnitude of the Effect

If the total resistance of a series resistance and instrument coil is 10,000 ohms, with an instrument designed to measure one milliampere for full scale deflection, the meter would now read ten volts for full scale deflection.

IV. References

1. Principles of Electrical Engineering, by Timbie & Bush.

2. Hausman, Erick, and Edgar P. Slack, Physics, D. Van Nostrand Co., Inc., New York, 1939, pp 368-370. A short statement of the law with illustrative problems.

See also: Skin Effect

Quantities

Current
Resistance, electrical
Voltage

OPTICAL ROTARY POWER

I. Description

Certain optically transparent materials cause the plane of polarization of light passing through the material to rotate. The materials which exhibit this property may be solids, liquids, or vapors. The rotation may be either dextrorotary (CW) or levorotary (CCW) depending upon the material and wave length. The angle through which the plane rotates is directly proportional to the length of path, the physical properties of the material, and inversely proportional to the wave length squared of the incident light. (Biot's Law)

The specific rotation of a given soluble compound is defined as the angle of rotation through which the plane of polarized light is turned in passing through a tube one decimeter of length, filled with a solution containing one gram of the substance per 1000 cubic centimeters. Both temperature and source of light must be specified. Generally 20°C is specified using the sodium D line.

II. Illustration

The concentration of a solution can be monitored by measuring the angle of rotation of plane polarized light passing through a given distance of the solution.

The saccharimeter is a special type of polarimeter used to analyze sugars. Dextrose is a simple sugar which rotates the plane of polarization to the right (CW).

Molecular structures of chemical compounds are studied and analyzed by their inherent optical rotary properties.

III. Magnitude of the Effect

For several materials, the rotary powers are:

Material	Rotation °/mm	
Quartz	21.68	at 5890 A.U. (Sodium)
Crystalline sucrose (table sugar)	235.97	at 2143 A.U. (Cadmium)
Crystalline sucrose (table sugar)	54	(Sodium D)
Sucrose solution specific rotation	.66	(Sodium D)
Turpentine	.37	(Sodium D)

A long column of vapor has the same rotary power as the short column of liquid into which it condenses, cross section remaining equal (Beer's Law).

IV. References

1. Hodgman, Charles D., Handbook of Chemistry & Physics, Chemical Rubber Publishing Co., Cleveland, Ohio, 1946, pp 2298-2300. Tables for various solutions.

2. Mac Dougall, Frank H., Physical Chemistry, The Macmillan Co., New York, 1935, pp 199-202. Cause and measurement.

3. Preston, Thomas, The Theory of Light, MacMillan & Co., Ltd., London, 1928, p 427. Qualitative discussion.

Quantities

Length
Material
Solution
Concentration
Wave Length
Temperature
Polarization

ORGAN PIPE RESONANCE

I. Description

For a closed pipe or other air column of length L where V is the velocity of sound in air, the frequencies of vibration for the fundamental and the first three overtones are:

$$F_0 = \frac{V}{4L} \qquad F_1 = \frac{3V}{4L} \qquad F_2 = \frac{5V}{4L} \qquad F_3 = \frac{7V}{4L}$$

For an open pipe:

$$F_0 = \frac{V}{2L} \qquad F_1 = \frac{2V}{2L} \qquad F_2 = \frac{3V}{2L} \qquad F_3 = \frac{4V}{2L}$$

Orifices may also be used to produce tones. For a rectangular opening of width d, the jet-tone produced has a frequency f of:

$f = 0.044 \frac{v}{d}$ for air Where: v is the velocity of the fluid

$f = 0.046 \frac{v}{d}$ for water

II. Illustration

A Kundt tube demonstrates organ pipe resonance and may be used to measure the velocity of sound in a gas by tuning a horizontal column of gas to resonance. Lycopodium or similar powder in the tube then collects at the nodes. The velocity of sound in the gas is:

$v = 2fd$ Where: v = velocity of sound in the gas
f = frequency
d = distance between nodes

III. Magnitude

The jet-tone is somewhat more productive of overtones (noise) than the resonant organ pipe. The intensity of the sound is limited by the energy supplied.

IV. References

1. Housmann, Erick, and Edgar P. Slack, Physics, D. Van Nostrand Co., Inc., New York 1939, pp 572, 553-555. Simple tube formulae.

2. Anderson, A. B. C., A Circular Orifice Number Describing Dependency of Primary Pfeifenton Frequency on Differential Pressure, Gas Density and Orifice Geometry, The Journal of the Acoustical Society of America, Vol. 25, No. 4, July 1953, pp 626-631. Tones generated by orifices.

Quantities

Frequency
Wave Length
Velocity of Sound
Length
Sound

PASCHEN'S LAW - 1889

I. Description

The sparking potential between two terminals in a given gas is a function of the product of the pressure and the spark length; i.e. upon the mass of gas between a unit area of the electrodes. This can be written:

$$V = f(pd)$$

where p = pressure of gas
d = spark length

It has been shown that Paschen's law holds for all pressures. These results are very important in that to find the sparking potential corresponding to any spark length and any pressure, it is only necessary to know the results of experiments made with a constant spark length over the whole range of pressures. Temperature does not affect this equation if the mass of the gas remains constant.

In all cases, the dimensions of the electrodes should be very large compared with the distance between them.

II. Illustration

For any given distance between electrodes in a gas, there is some critical pressure at which discharge occurs at the minimum sparking potential of the gas. Thus with a gap 3 mm in air, spark-over occurs at a pressure of 1.5 mm at about 340 volts. For a gap of 1 mm the discharge occurs at a pressure of 5 mm at the same voltage. At pressures above and below these minima, or critical pressures, the voltage necessary to produce a breakdown of the gas increases with both increasing and decreasing pressures. This effect is important for internal combustion engines.

III. Magnitude of the Effect

Gas	Min. Spark Potential	Pxd in mmxmm
air	341	5.7
N_2	251	6.7
H_2	278	14.4
O_2	455	

IV. Reference

1. Crowther, James Arnold, Ions, Electrons and Ionizing Radiation, University Press, Cambridge, England, 1946. pp 66-67. Short derivation of the law.

Quantities

Gas
Length
Material
Pressure
Voltage

PERIODIC LAW (OR TABLE) (1869)

I. Description

If the elements are arranged in order of atomic number (electrons), a periodic repetition of their chemical and physical properties is apparent.

II. Illustration

Group I contains hydrogen, lithium, sodium, potassium, rubidium and cesium in order of increasing atomic weights. All of these materials display a valance of $+1$ (similar chemical behavior) and are very active chemically. Similarly the inert gases, helium, neon, argon, krypton, and xenon occupy similar positions. Physical properties are also similar as given by the photoelectric effect (alkali metals) and electrical conductivity (silver, copper).

III. Magnitude

The arrangement of the elements will give only qualitative results regarding behavior, but the arrangement of the electrons in the various shells also limits the spectra produced by the atom.

IV. References

1. MacDougall, Frank H., Physical Chemistry, The Macmillan Co., New York 1935, pp 173-190. Usefulness and limits of periodic table.

Quantities

Atomic Weight
Material
Radiation

PHOTOELECTRIC EFFECT

I. Description

A. There are three types of photoelectric effects:

1. Photoemissive effect - emission of electrons from metallic surfaces when radiation impinges upon the surface. The current is proportional to the illumination for intensity ranges of 50,000 to 1. (Not true for polarized light.)

2. Photovoltaic effect - generation of a voltage across the boundary between two metals when radiation strikes this boundary.

3. Photoconductive effect - change in resistance of a semi-conductor as a result of incident radiation.

B. All these effects follow Einstein's (or Millikan's) photoelectric equation:

$$hf = w + \left[\frac{\frac{1}{2} m_o v^2}{\sqrt{1 - \left(\frac{v}{c}\right)^2}} \right]$$

where m_o = rest mass of electron
h = Planck's constant
f = frequency of incident radiation
w = work function of the emitter
v = velocity of electron
c = velocity of light

Since the work function is the energy required to move an electron away from the surface of the emitter, it is seen that there is a lower frequency limit below which no electrons will be emitted and thus no photoelectric effect will be observed. Above this critical level the frequency response depends upon the construction of the cell.

Notice that radiation such as X-rays, gamma rays (not light), is the causative factor. The actual current flow, or voltage generated, is a function of amount of radiation, i.e., incident radiant flux.

Historically this effect appears with various names. Hertz, as well as Wiedemann and Ebert found that illuminating the cathode of a gap will facilitate the sparking. Elster & Geitel found (as did Hertz) that negatively charged substances lose their charge when illuminated by ultraviolet, or bodies initially uncharged gain a positive potential under this light.

II. Illustration

A. The light meter uses a photovoltaic cell as a source of current to drive a D.C. meter. Deflection of the meter is proportional to the light flux falling on the face of the cell.

B. The photoemissive type cell is generally used in the sound system of motion picture machines. Density variations of the sound strip on the film produce variations in the amount of light striking the cell. This causes a signal to be generated which is amplified and converted to sound.

C. The photoconductive type cell is not yet in common use. Selenium and germanium are often used in this type of cell.

III. Magnitude of the Effect

A. Photoemissive type cells have a sensitivity of up to 500 volts per lumen of light incident to the cell surface. Gas filled phototubes have about double this value.

B. The photovoltaic cell has an output of about 500 microamperes per lumen with a very low resistance load. The voltage output is low, the maximum being about 0.4 millivolts per lumen.

C. The resistance of the photoconductive type cell is between .1 to 25 megohms and can vary as much as 25 to 1 from its no light to maximum light condition. The current range is below 500 M.A.

III. Magnitude of the Effect (Cont)

D. For some metals like platinum the energy required to pull an electron away from the surface is large, whereas for other metals like the alkalis it is quite small; W the work function varies:

	Work Function Electron Volts
Caesium	1.81
Lithium	2.36
Molybdenum	4.15
Tungsten	4.54
Strontium oxide	1.27

IV. References

1. Richtmyer, E. K. and E. H. Kennard, Introduction to Modern Physics, McGraw-Hill Book Co., Inc., 1947, pp 87-96. A general discussion with equations.

Quantities

Energy
Material
Frequency
Velocity of Light

PHOTOMAGNETIC EFFECT

I. Description

Some salts show a slight increase in their paramagnetic behavior after exposure to light. One type of Hall effect near absolute zero generates a voltage in cuprous oxide perpendicular to both of the mutually perpendicular incident white light and magnetic field.

II. Illustration

The paramagnetic behavior is observable for chromic chloride.

III. Magnitude

There is some question as to whether the paramagnetic effect exists as its magnitude is relatively small. The photomagnetic Hall effect produces a voltage as a linear function of the field up to 2500 gauss, the voltage there being 2.7 volts.

IV. Reference

1. Bhatnagar, S. S. and K. N. Mathur, Physical Principles and Applications of Magnetochemistry, MacMillan & Co., Ltd., London, 1935, pp 279-280. A presentation of the conflicting evidence; p 292, The photomagnetic Hall effect.

See also: Hall Effect

Quantities

Current
Magnetic Flux
Permeability
Radiation
Light, visible
Temperature
Voltage

Electricity & Magnetism
Mechanics

PIEZOELECTRIC EFFECT

I. Description

Certain crystals become electrified when subjected to compression or tension. The electric charges developed on the faces of the crystal are proportional to the pressure. This is particularly of use in measuring high frequency pressures or steep wave-front transients, where ordinary devices would have too much inertia.

Electrostriction is the converse; an electric field alters the shape of such a crystal. If an alternating electric field applied to such a crystal has a frequency near the natural mechanical frequency of the crystal, these mechanical vibrations become very large. This serves as a source of frequency stabilization for radio transmitters. Most dielectrics demonstrate electrostriction, but not piezoelectricity.

II. Illustration

A crystal placed in the grid circuit of a vacuum tube oscillator serves as an excellent source of frequency stabilization. This effect is also used in ultrasonic transducers, microphones, phonograph pickups, and earphones.

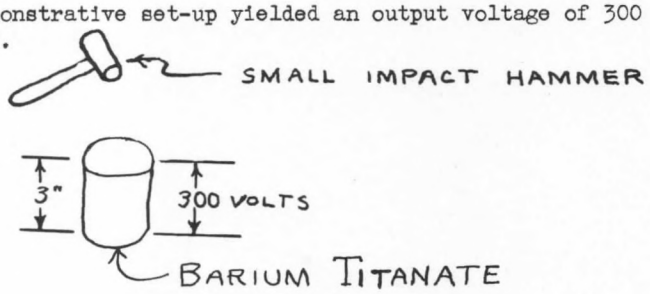
III. Magnitude of the Effect

A) The Q of such crystal oscillators varies from a few thousand to as high as 500,000.

B) The following is piezoelectric data on Barium Titanate:

Conversion of mechanical energy to electrical energy --- 25 to 40%
Conversion constant --- 150 x 10^{-12} coulombs/newton

The following demonstrative set-up yielded an output voltage of 300 volts for a very short period.



IV. Reference

1. Wooster, W. A., A Text-Book on Crystal Physics, The University Press, Cambridge, England, 1949. pp 188-222. Theory, testing and uses.

Quantities

Charge
Force
Voltage
Vibration
Energy

PINCH EFFECT

I. Description

The passage of an electric current through a liquid conductor tends to reduce the cross-section of the conductor. This effect can be explained by considering that an infinite number of parallel conductors carrying current in the same direction will attract each other. This force will tend to reduce the conductor area.

The pressure, P, at the center of conductor of circular cross-section due to the pinch effect is given by:

$$P = \frac{(10\,I)^2}{S} \quad \frac{\text{dynes}}{\text{cm}^2}$$

I = current, amperes.
S = cross-sectional area, square centimeters.

II. Illustration

This effect is noticeable when high conductivity metals are heated in an induction furnace of the type where the metal forms the secondary turn on the transformer. To be liquified, these metals require very high current densities at the part of the channel that presents the smallest initial cross-section, hence the force of contraction will then be the greatest. As the cross-section reduces, the force progressively increases so that the metal may even be severed. The observed effect will be a rapid opening and closing of a gap in the fluid. The resultant decreases in average current usually allow the metal to freeze.

This effect might be put to use as a current limiting device using mercury in a small tube.

III. Magnitude of the Effect

The table below gives the maximum currents that can be passed through liquid iron in channels of three sizes.

DEPTH, inches	WIDTH, inches	CURRENT, amperes
2	1	3300
4	2	9400
6	3	17000

IV. References

1. Thompson, M. D. K., Theoretical and Applied Electrochemistry, The Macmillan Co., N. Y., 1925, p 383.

2. Liddell, D. M., Handbook of Non-Ferrous Metallurgy, McGraw-Hill Book Co., Inc., 1926, Vol. 1, p 619.

3. Koehler, W. A., Principles and Application of Electrochemistry, John Wiley & Sons, Inc., 1944, Vol. 2, p 424.

Quantities

Area
Current
Force
Pressure
Resistance, electrical
Temperature

POISSON'S COEFFICIENT (OR RATIO)

I. Description

The longitudinal stretching of any elastic material is accompanied by a lateral contraction, and the ratio of the contraction to the proportional stretching is known as Poisson'e coefficient. The proportional stretching or unit elongation (elongation per unit of length) is the strain in the material, and may be denoted by S. Calling Poisson's coefficient M:

$$\text{lateral contraction} = M \times S$$

hence lateral dimensions diminish by a percentage equal to 100 MS.

II. Illustration

For materials in which there is no "grain" to elasticity, the value of Poisson's ratio was demonstrated by that celebrated mathematician to be 0.25 and actual cases bear out his deductions closely. For most metals it lies between 0.25 and 0.33. If the volume remained constant, M would be .50; therefore the volume of most metals increases slightly when loaded in uniaxial tension and decreases when loaded in uniaxial compression.

III. Magnitude

For some common materials, Poisson's ratio is:

Steel	.278 - .305
Cast Iron	.211 - .299
Copper	.355
Brass	.331
Aluminum Alloys	.330 - .334

The shear modulus G, Poisson's ratio and Young's modulus E are related:

$$G = \frac{E}{2(1 + M)}$$

IV. References

1. Young, J. I., Materials & Processes, John Wiley & Sons, Inc., New York, 1949. p 48. Short definition.

2. Timoshenko, S., and J. N. Goodier, Theory of Elasticity, McGraw-Hill Book Co., Inc., 1951. pp 254-5. Method of determining ratio by the use of beams.

3. Hetenyi, M., Handbook of Experimental Stress Analysis, John Wiley & Sons, Inc., N. Y., 1950. pp 767-770. Poisson's ratio in dealing with scale models.

Quantities

Displacement, linear
Force
Length
Volume

PROXIMITY EFFECT

I. Description

When a wire is carrying an alternating current, or in general any current whose magnitude is varying, the current has a tendency to crowd toward one side of a conductor owing to the proximity of another current-carrying conductor. This effect increases the resistance much the same as skin effect. The effect on inductance is practically negligible when the spacing between wires is large compared to the diameter of the wire.

II. Magnitude of the Effect

The effective resistance of the line is given by:

$$R_{eff} = \frac{134\ F \times f}{r} \times 10^{-4} \text{ ohms/mile}$$

where f = frequency in c.p.s.
r = radius of the wire
d = distance between the centers of the wires
F = experimental factor -

Data for curve of F versus (d-r)/r

(d-r)/r	F
4	1.15
6	1.06
8	1.037
12	1.02
16	1.01
20	1.002
32	1.--

III. Reference

1. Ware, L. A. and Reed, H. R., Communication Circuits, John Wiley & Sons, Inc., 2nd Edition, 1944, page 15.

Quantities

Current
Electric Field
Radius
Resistance, electrical

PURKINJE EFFECT

I. Description

The human eye is less sensitive to light of longer wave lengths under conditions of decreased illumination.

II. Illustration

This effect complicates visual determination of celestial magnitudes of different colored stars. It is a source of difficulty in the manufacture of color photography emulsions due to the varying degrees of contrast required for different wave lengths.

Violet and blue lights can be detected at greater distances by a dark adapted eye than red lights. Blackout filters are red, not blue or green, to reduce possibility of light detection by the enemy.

Dark adaption occurs in the short wave range of the spectrum. Red goggles are worn so that the eyes may dark adapt while still in use for map reading or briefing prior to night operations.

This effect may be useful in displays and advertising. Tail lights should be half violet, half red for best day and night usefulness. Relative visibility colors can be selected for clothing, paint, lights, etc., depending on day or night use.

III. Magnitude of the Effect

Red, orange and yellow appear brightest under moderate illumination. A red (670 mu*) may be 10 times brighter to a light adapted eye than a blue (480 mu). Decreasing light intensity to 1 lumen/sq. ft. begins a sensitivity shaft into the greens. At .1 lumen/sq. ft., a dark adapted eye sees the blue 16 times brighter than the red.

* 1 mu = 10^{-7} cm.

IV. References

1. Jacobs, Donald H., Fundamentals of Optical Engineering, McGraw-Hill Book Co., Inc., N. Y., 1943. pp 81-84. Law and related effects.

2. Luckiesh, Matthew & Frank K. Moss, The Science of Seeing, D. Van Nostrand Co., Inc., N. Y., 1937. pp 62, 66-71. Dark adaptation.

Quantities

Color
Energy
Light, visible
Stimulus

PYROELECTRIC EFFECT

I. Description

Charges appear at the ends of certain crystals when their temperature is changed. The polarity of these charges reverse when the direction of temperature change is reversed. The induced potential is proportional to the temperature change, not the rate of change.

II. Illustration

A very small crystal could be used to measure transient temperature effects. The voltage so developed could be used to operate an a.c. electronic amplifier. Temperature differences in quarty produce charges, but this is a piezo-electric effect. Crystals which exhibit pyroelectricity are cane sugar calamine, boracite, pentalrythrital and some kinds of topaz.

III. Magnitude of the Effect

Tourmaline crystals develop 300 volts per cm for each ^{o}C. The actual charge, however, is very small.

IV. Reference

1. Wooster, W. A., A Text-Book on Crystal Physics, University Press, Cambridge, England, 1949. pp 223-230. Quantitative description and discussion.

Quantities

Charge
Electric Field
Heat Flow
Temperature
Temperature Gradient

QUANTUM THEORY (1900)

I. Description

1. This law states that radiation is emitted in discrete bunches or quanta whose individual energy is $E = f\,h$

   where f = frequency of radiation
   h = 6.61×10^{-27} erg. sec.

   This equation is also known as Einstein's frequency condition.

2. Using the quantum idea as a basis, the Planck Radiation Law was derived which expresses the radiation intensity of a given wave length.

   Approximately: $$\psi_\lambda = \frac{8\pi ch}{\lambda^5} \quad \frac{1}{e^{ch/\lambda kT} - 1}$$

   where ψ_λ = radiation intensity at one wave length λ
   k = Boltzmann constant 1.381×10^{-16} erg/degree
   T = absolute temperature degrees Kelvin
   λ = wave length in centimeters
   c = velocity of light 2.9978×10^{10} cm/sec

II. Illustration

All electromagnetic waves, including radio, follow this law. This theory is also the basis for the photoelectric effect.

III. Magnitude

The various electrons in an atom occupy various energy positions. It is only when the electrons transfer from one position to the other that a quanta of energy is liberated. The energy state is defined by quantum number, four being required to describe the state of any electron. Paule's exclusion principle states that only one electron in the atom may occupy a quantum state.

Reference

1. Richtmyer, F. K. and E. H. Kennard, Introduction to Modern Physics, McGraw-Hill Book Company, Inc., New York, 1947. pp 178-183, 204 derivation. See also pp 235-287 for wave mechanics.

Quantities

Energy
Frequency
Radiation
Velocity of Light
Wave Length

RADIATION PRESSURE

I. Description

Electromagnetic waves carry momentum. Thus, for an absorbing surface, radiation pressure is:

$$p = \frac{n I}{c}$$

or

$$p = w \cos^2 \theta$$

p = dynes per cm^2
n = refractive index of medium of $\frac{c}{v}$
I = intensity of radiation
c = velocity of light in free space
v = velocity of propagation in medium
w = energy density of the radiation
θ = angle of radiation from normal to surface

II. Illustration

It probably should be pointed out that the radiometer does not operate because of radiation pressure, but in spite of it. The curvature of comet's tails is due to this cause, however.

III. Magnitude

The force is small, being about 2×10^{-5} dynes per cm^2 for sunlight.

IV. Reference

1. Richtmyer, F. K., and E. H. Dennard, Introduction to Modern Physics, McGraw-Hill Book Co., Inc., New York, 1947, pp 58-60. Derivation of the formula.

Quantities

Light, visible
Pressure
Radiation
Velocity of Light

RADIOACTIVITY

I. Description

The nuclei of some materials may be either naturally or artificially unstable, emitting, with time, helium nuclei (alpha particles), electrons (beta rays) or gamma rays (x-rays) and changing to a new element. This degeneration is unaffected by heat or pressure. The alpha particles have a range proportional to the third power of their initial velocity, but even this is short, as a sheet of paper is an effective screen. Since there is a constant probability for each atom to break down, the speed of this process is proportional to the number present, or:

$$\frac{d N_o}{dt} = -\lambda N_t$$

where N_t = number atoms present
λ = a constant

The half-life of a material is the time required for one-half the atoms initially present to break down.

II. Illustration

In industry, gamma ray emitters, as they may be called, are used to examine castings for flaws and imperfections; they are used to control steel plate thickness in the rolling mills; and they are used in the oil fields to examine the strata above oil pools to aid geologists in finding new oil sites.

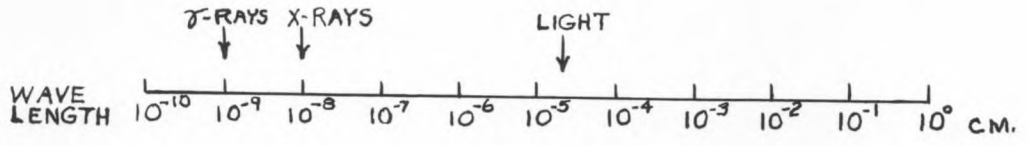
Since the percentage of the rays which pass through a substance is a direct function of the thickness of the substance, gamma rays are useful in controlling the thickness of steel plate in a rolling mill. By picking up the rays after they have passed through the steel sheet with a Geiger counter or a scintillation counter and properly amplifying the resulting voltage, a control voltage may be obtained to regulate the position of the rollers. Beta rays have also been used for gaging the thickness of foils.

More extensive use of gamma rays is limited by the extreme care which must be taken to protect workers from harmful radiation. The shielding required and the precautionary measures taken cost more, perhaps, than the radioactive substance with its associated recording or indicating equipment. While alpha particles are powerful ionizers they are poor penetrators, for they will travel only 3 to 9 cm. in air and are stopped by an aluminum foil 0.1 mm. thick.

Electrons, or the beta particles have a mass of 1/1845 that of the hydrogen atom. They travel at an initial velocity of 33-99% of the speed of light, but because of their low mass, their path is very erratic and every collision bounces them off in another direction. They are poor ionizers compared to alpha particles, but will penetrate several feet of air and up to 5 mm of aluminum.

Gamma rays will pass thru iron one foot thick and are not affected by electrostatic or magnetic fields. They produce photographic effects, luminescence, and ionization, and are similar to very high velocity, or hard x-rays.

The logarithmic graph below will give some idea of the wave length of these gamma rays. The shortest light wave visible to the eye has a wave length of about 4000×10^{-8} cm., while gamma rays are about 10^{-9} cm. in length.



It should be evident that gamma rays are most useful of the three for industrial applications. They may interact with atomic nuclei and change direction without any energy transfer. They may impart all or part of their energy to electrons, causing them to be expelled from their parent atoms with sufficient energy to produce many more ions. Or, if they possess sufficiently high energy (16.18×10^{-14} Joules), the quantum may be transformed into an electron and a positron. Thus energy is destroyed and mass created.

IV. References

1. Goodman, Clark, The Science and Engineering of Nuclear Power, Vol. 1, Addeson-Wesley Press Inc.

2. Holliday, David, Introductory Nuclear Physics, John Wiley and Sons, Inc., New York, 1950.

3. Richtmeyer, F. K. and E. H. Kennard, Introduction to Modern Physics, McGraw-Hill Book Co., Inc., 1947, pp 553-561. History and characteristics of radioactivity.

4. Glasstone, Samuel, Sourcebook on Atomic Energy, D. Van Nostrand Co., Inc., New York, 1950, pp 50-55. Discussion of several phases. pp 109-129, Natural radioactivity.

Quantities

Charge
Energy
Radiation
X-rays

RAOULT'S LAW

(Includes Babo's Law)

I. Description

According to Babo's law, the vapor pressure of a solvent is lowered on dissolving the solute. This lowering of vapor pressure for dilute solutions is proportional to the mole concentration of the non-volatile solute. Raoult then related the lowering of the vapor pressure of the solution to the lowering of the freezing point and the elevation of the boiling point. The change in boiling and freezing points is constant, for a given solvent, and dependent only on the concentration of the solute, not the kind.

II. Illustration

This phenomena serves as a basis for molecular weight determinations.

If both components of a solution are volatile, each will lower the vapor pressure of the other and the ratios of the two substances in the liquid and vapor phases will not necessarily be the same. Use is made of this fact to separate the two substances by distillation.

The addition of table salt (N_aCl), which is non-volatile, to distilled water would lower the vapor pressure in proportion to the amount of salt dissolved.

The resulting lower vapor pressure must reduce the rate of evaporation of the solution and this reasoning finally explains why old-timers put salt in their beer.

III. Magnitude

The effect is independent of temperature; the per cent difference between vapor pressure of the solution and that of the pure solvent is the same for all temperatures. The change (°C) in boiling point t_b and freezing point (t_f) per mole of solute for 100 g. of several solvents follows:

Solvent	t_b	t_f
Ethyl Alcohol	1.20	-
Benzene	2.57	5.12
Water	.511	1.860

IV. References

1. Mac Dougall, Frank H., Physical Chemistry, The Macmillan Co., New York, 1936, pp 239-241, 243-244. Raoult's Law and limitations.

2. Eggert, John, Physical Chemistry (translated by S. J. Gregg), Constable & Co., Ltd., London, 1932, pp 244-247. Babo & Raoult's Law; Relation.

See also: Arrhenius Theory of Electrolytic Dissociation

Quantities

Concentration
Gas
Molecular Weight
Pressure, partial
Solutions
Vapor Pressure
Boiling Point
Freezing Point

RESIDUAL VOLTAGE

I. Description

A unique property of Bismuth, Antimony and Tellurium is their ability to retain a small amount of residual voltage when the applied potential has been removed. A magnetic field influences the voltage slightly.

II. Magnitude of the Effect

About 1% of the applied voltage remains for one to three seconds. Very little is known about this phenomenon and to date no application has been made.

III. Reference

1. Geipel, H., The Behavior of Bi, Sb, & Te with A.C. and D.C., Ann Der Physik Vol. 38, May 7, 1912 pp 149-205. An abstract in English appears in Science Abstracts 1912, Volume A, Abstract No. 1095.

Quantities

Charge
Current
Voltage
Time

RESISTANCE / DIMENSION

I. Description

When a material undergoes a change in dimension, but is not strained the change in resistance will be proportional to the length and inversely proportional to the cross sectional area. If the material is strained an additional factor will enter into the calculations.

II. Illustration

If fine wire is mounted to a paper backing, and then the entire unit attached to some material, the unit can be used as a very sensitive means of determining the strain in that material. Such a device finds wide use in aircraft structural work.

III. Magnitude of the Effect

A strain measuring device as described in the illustration has a change in resistance of 2 to 3.5 times the change in length of the material. (i.e. $\frac{R_2/L_2}{R_1/L_1}$ = 2 to 3.5)

IV. Reference

1. Hetenyi, M. I., Handbook of Experimental Stress Analysis, John Wiley & Sons, 1950. pp 170-175. This section covers metallic resistance gages, mathematically and in practice. The general use of this type of gage is covered on pages 160-237.

See also: Skin Effect.

Quantities

Length
Resistance, electrical
Strain & Stress

RESISTANCE / TEMPERATURE

I. Description

The resistance of all pure metals increases as the temperature of the metal is increased. The resistivity of non-metals and electrolytes decreases as their temperature is increased.

II. Illustration

The variation of resistance with temperature for pure metals is linear enough to be represented by a temperature coefficient of resistivity. Heat treatment or mechanical strain may have a marked effect on the coefficient of a given metal.

$$\rho = \rho_0 + at$$

Temperature coefficients for alloys should be used within the range of ordinary temperatures. For instance, the coefficient for Nichrome (0.00017 /°C) gives accurate results up to 450°C. But from 450 to 1000°C, there is no change in resistivity and the coefficient would give erroneous results. Manganin is an alloy for which the coefficient is essentially zero throughout the range of ambient temperatures. It is used in precision instruments, shunts, and laboratory standard resistors.

The formula for resistance does not hold for some materials such as mercury, tin, lead, zinc aluminum, cupric sulfide, tungsten carbide and columbium nitride which become nearly perfact conductors near absolute zero (15°K and below). Use of this effect is made in bolometers, high "Q" resonators and low noise level photoconductors.

Non-metals and solutions of acids and salts are not sufficiently linear to apply a temperature coefficient over any appreciable range. In general, their resistance varies with temperature as:

$$\rho = \rho_0 + at + bt^2 + ct^3 + \ldots$$

and the terms in t^2 and higher powers cannot be neglected.

III. Magnitude of the Effect

Some temperature coefficients of resistivity taken at 20°C are:

	a
Aluminum	0.004
Copper	0.0039
Mercury	0.0008
Silver	0.004
Tungsten	0.005
Manganin	0.00002
Tophet A (80 Ni, 20 Cr)	0.05
Rubber (range: 10 - 30°C)	0.04
Varnished Cambric (range: 10 - 30°C)	0.07

IV. References

1. Hehre and Harness, Electrical Circuits and Machinery, Vol. 1, pp 97-102.

2. Little, Arthur D., Low Temperatures in Electronics, Electronics July 1953, Vol. 26, No. 7, pp 222-230. A qualitative review of current knowledge.

3. Austin, A. V. (Director), Low Temperature Physics, National Bureau of Standards Circular 519, October 6, 1952, Washington, D.C. A total of 61 papers on various aspects of low temperature phenomena, a number of which deal with super conductivity.

Quantities

Resistance, electrical
Temperature
Material

RICHARDSON'S EFFECT (Edison Effect)

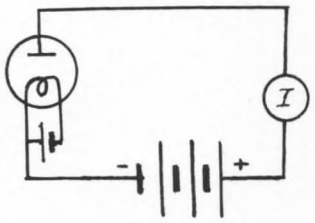
I. Description

There is a current of negative electricity, increasing rapidly with the temperature, flowing from all metallic conductors at a temperature of more than 1000°C to surrounding conductors, even if the intervening space is completely vacuous. Knowledge of the existence of this current is chiefly due to Richardson. The study of this subject is given the name of thermionics.

The number of electrons emitted per unit time increases with the temperature of the filament and depends upon the substance of which it is made. The rate of electron emission is expressed as the current per unit of surface area of the hot body.

$$I = AT^2 \varepsilon^{-b/T}$$

I = amperes/sq. cm.
T=K = temperatures in degrees Kelvin
A = constant for pure metal hot bodies is 60.2
b = constant, experimentally determined



II. Illustration

This current was first detected by Edison as a blue or purple glow inside an imperfectly exhausted carbon filament lamp. He studied the effect by adding another electrode (the plate) into the bulb, building a rectifier.

As first observed by Edison and for most vacuum tubes today, the current is a small fraction of an ampere, but modern thyratrons may carry 100 or more amperes.

III. Magnitude of the Effect

Some representative values of the thermionic emission constants are:

	A	B	Melting Point °K
Calcium	60.2	26,000	1,083
Carbon	60.2	46,500	3,773
Caesium	16.2	21,000	299
Molybdenum	60.2	51,500	2,893
Nickel	26.8	32,100	1,725
Platinum	60.2	59,000	2,028
Tontalum	60.2	47,200	3,123
Thorium	60.2	38,900	2,118
Tungsten	60.2	52,400	3,643

IV. References

1. Richtmyer, R. K. and E. H. Kennard, Introduction to Modern Physics, McGraw-Hill Book Co., Inc., 1947, pp 96-99. Various aspects of thermionic emission.

2. Wright, D. A., A Survey of Present Knowledge of Thermionic Emitters, The Proceedings of the Institute of Electrical Engineers, Vol. 100, No. 65, Part III, May 1953, London. pp 125-142. A review of present knowledge.

3. Zemansky, Mark W., Heat and Thermodynamics, McGraw-Hill Book Co., Inc., New York 1943, pp 296-299. Application of sublimation equation to electron gas.

Quantities

Current
Temperature
Material
Area

SCHRODINGER'S WAVE EQUATION

I. Description

This equation relates the properties of matter which at times suggest that matter is corpuscular, and at other times suggest that matter is an electromagnetic wave. The equation is:

$$-\frac{h}{2\pi i}\frac{\partial \Psi}{\partial t} = -\frac{h^2}{8\pi^2 m}\left(\frac{\partial^2 \Psi}{\partial x^2} + \frac{\partial^2 \Psi}{\partial y^2} + \frac{\partial^2 \Psi}{\partial z^2}\right) + V\Psi$$

Where Ψ = equation of the wave
V = potential energy function of particle
h = Planck's constant = 6.610×10^{-27} erg sec
t = time
x, y, z = three coordinate directions
i = $\sqrt{-1}$
m = mass of the particle

II. Illustration

The equation is similar to those obtained for heat flow in a body. No solutions to Ψ can have a simple sine or cosine function.

III. Magnitude

Reference should be made to the simpler De Broglie equations to determine the wave length of the particles, $\lambda = \frac{h}{mv}$ where λ is the wave length; m = mass of particle; v = velocity. These equations are important only when dealing with small particles at high velocities; example, electrons in tubes.

IV. Reference

1. Richtmyer, F. K. and E. H. Kennard, Introduction to Modern Physics, McGraw-Hill Book Co., Inc., New York, 1947, pp 259-267. Derivation and physical significance. See also pp 244-248 for De Broglie equations.

Quantities

Displacement, linear
Energy
Frequency
Mass
Motion
Time
Wave Length

SHOT EFFECT (SCHOTTKY EFFECT)

I. Description

Shot noise is generated in electron tubes because electrons emitted from the cathode are random in time and velocity. Thus, the plate current is not exactly uniform, the shot noise components being distributed uniformly in frequency as is thermal agitation noise. The voltage variation developed is termed the shot effect.

II. Illustration

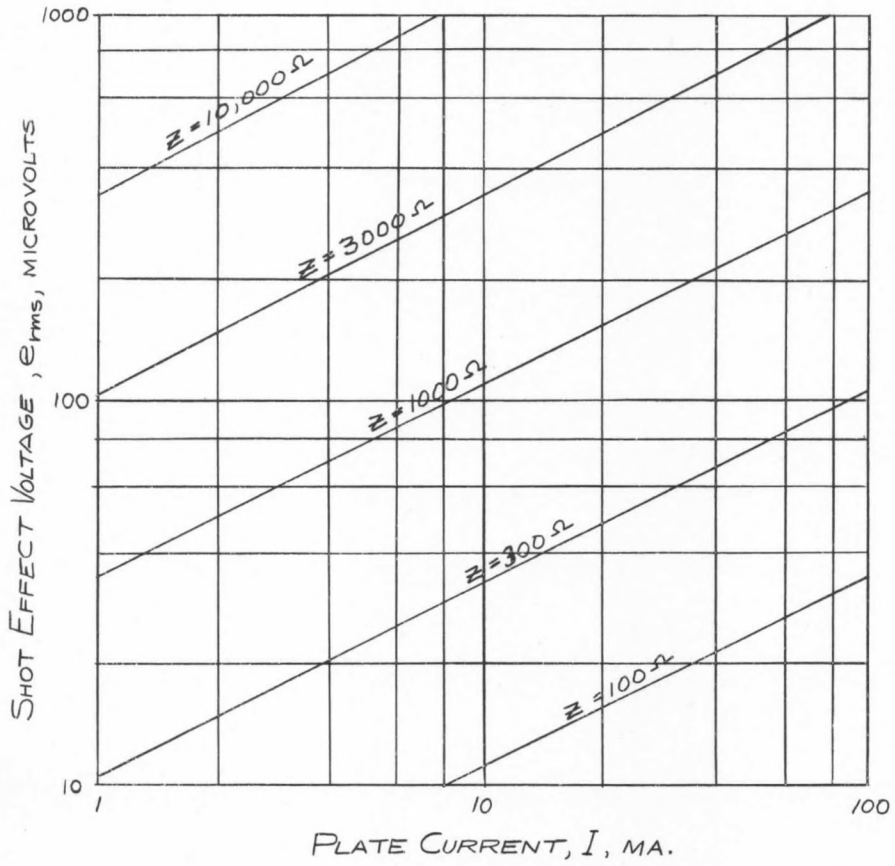
This shot noise or shot effect is an important factor in limiting the maximum permissible gain from amplifiers, since it may well mask the signal.

III. Magnitude

For temperature limited emission in a diode, the voltage variations are

$$\overline{E}^2 = 3.18 \times 10^{-19} \, I \, Z^2 \, df$$

where $\overline{E}^2$ = mean square shot effect voltage
I = electron current, amperes
Z = resonant impedance of the tuned circuit
df = frequency bandwidth factor



IV. References

1. M.I.T. Radar School Staff, Principles of Radar, McGraw-Hill Book Co., Inc., N. Y., 1946. pp 4-9.

2. Lawson, James L., and George E. Uhlenbeck, Threshold Signals, McGraw-Hill Book Co., Inc., 1950, pp 64-97. Thermal and shot noises.

Quantities

Current
Motion
Noise
Sound
Temperature
Voltage

SKIN EFFECT*

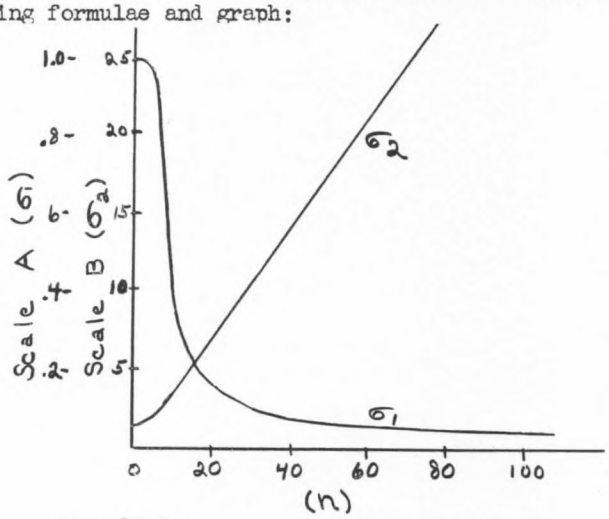
I. Description

When a wire is carrying an alternating current, or in general any current whose magnitude is varying, the current has a tendency to crowd toward the surface of the wire. The result will be a reduction of the inductance and an increase in the ohmic resistance of the conductor.

The existence of this effect may be seen from the following analysis. Assume the wire to be divided into a large number of very small circular elements all exactly alike and parallel to the conductor axis. Assume also that the wire is carrying a current which is uniformly distributed throughout the cross section and that this current begins to increase in value. The elements near the axis have more flux encircling them and hence have a higher self-inductance (because of the higher number of flux linkages) than those near the surface. Hence an easier path for current will lie toward the surface of the conductor, and since the material is uniform, the current will seek to flow in this easier path. This effect does not hold true at temperatures near absolute zero.

II. Magnitude of the Effect

The correction factor to be applied to the inductance and resistance of a solid round wire is given from the following formulae and graph:



$$n = a\sqrt{\frac{8\pi^2\mu f}{\rho}} \qquad n = 0.214\ a\sqrt{f} \quad \text{(for copper)}$$

where a = wire radius in cm.
f = frequency in c.p.s.
μ = resistivity in abohms/cm^3
ρ = permeability

Inductance for parallel wires

$$L = \sigma_1 \quad (1.482) \log \frac{d-r}{r} \quad \text{millihenry/mile}$$

where d = distance between wires
r = radius of wire

Resistance

$$R_{eff} = \sigma_2 \quad R_{D.C.}$$

III. References

1. Ware, L. A. and Reed, H. R., Communication Circuits, published by John Wiley & Son, Inc, 2nd Edition, 1944, page 11.

2. Austin, A. V. (Director), Low Temperature Physics, National Bureau of Standards Circular 519, Washington, D.C., Approximate Calculations of the Surface Impedance of a Metal in the Anomalous Region, by P. M. Marcus, pp 265-272. Theory, and results for low temperatures.

*See also: Proximity Effect

Quantities

Inductance
Current
Material
Permeability
Resistance, electrical
Temperature

Optics
Chemistry
General Physics

SNELL'S LAW - 1621

THE LAW OF REFRACTION

I. Description

A) When light passes from one medium to another, the incident ray, the normal to the surface at the point of incidence, the reflected ray and the refracted ray are all in the same plane.

B) The sine of the angle of incidence bears to the sine of the angle of refraction a ratio which is constant for the same two media, and depends only on the nature of those media.

$$\frac{v_i}{v_r} = \frac{\text{Sin } i}{\text{Sin } r} = \frac{n_r}{n_i} \text{ ; index of refraction if } \underline{i} \text{ is for air}$$

i = angle of incidence (measured from a normal)
r = angle of refraction (measured from a normal)

For light traveling from a material of high to a material of low index of refraction, the light is totally reflected if the angle of incidence exceeds a limiting critical angle (See Total Reflection).

C) The variation of the index of refraction of a medium with wave length will cause a spreading of the component wave lengths in a beam of radiation (as with a prism). This spreading is termed dispersion.

D) Specific Refraction r or Refractivity

$$r = \frac{1}{d}\frac{n^2 - 1}{n^2 + 2}$$

n = refractive index
d = density of the liquid
} at the same temperature

E) Molar Refraction R

$$R = \frac{M}{d} \cdot \frac{n^2 - 1}{n^2 + 2}$$

M = molecular weight

The molar refraction theoretically stays constant for all temperatures. This equation gives the approximate measure of the volume occupied by the molecules in a molar volume of the substance.

II. Illustration

All lenses (not reflectors) depend upon refraction to obtain their action. Dispersion, which causes chromatic aberration in lenses, is utilized by prisms to form spectra. Refraction is also used for micro-wave lenses.

III. References

1. Page, Leigh, Theoretical Physics, D. Van Nostrand Co., Inc., New York, 1935, pp 552-557. Mathematical treatments of refraction at plane and spherical surfaces, pp 558-562, Lenses.

2. Hausmann, Erick, and Edgar P. Slack, Physics, D. Van Nostrand Co., Inc., New York 1939, pp 609-612, An understandable discussion (with mathematics), including the effect of flat plates.

3. Mac Dougall, Frank H., Physical Chemistry, The Macmillan Co., New York, 1935, pp 194-5. Description and one example of specific and molar refraction.

See also: Diffraction
Gladstone & Dale's Law
Total Reflection

Quantities

Angle, incidence	Index of Refraction	Wave Length	Molecular Weights
Angle, refraction	Light, visible	Density	Molecules
Temperature	Velocity of Light		

STARK EFFECT

I. Description

The spectral lines emitted when the source is in a strong electric field are split and polarized. The effects vary with field intensity and with the direction between the direction of emission and the electric field.

In many respects this resembles the more complicated types of Zeeman effect, but is subject to different laws, and the lines change in character radically and in multiplicity of component lines with increasing field intensity.

II. Illustration

When the hydrogen lines Hα and Hβ are under observation in a direction perpendicular to the electric field three evenly spaced lines appear which are unpolarized.

III. Magnitude

The hydrogen violet line separates as much as 33 angstrom units apart for a field 74,000 volts/cm. This splitting of the spectral lines is linear with the square of the applied field strength.

IV. References

1. Richtmyer, F. K. and E. H. Kennard, Introduction to Modern Physics, McGraw-Hill Book Co., Inc., 1947, pp 388-9. Description of apparatus.

2. White, Harvey Elliott, Introduction to Atomic Spectra, McGraw-Hill Book Co., Inc., N. Y., 1934, pp 401-407. Theory, some mathematics and some examples.

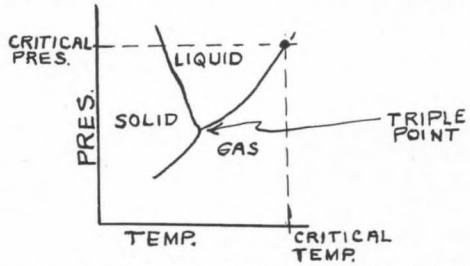
Quantities

Electric Field
Material
Voltage
Wave Length

STATE AND CHANGE OF STATE

I. Description

Matter may exist in three forms or phases; solid, liquid, and gas. The highest temperature and pressure at which all three of these states may co-exist in equilibrium is called the triple point. The highest temperature at which a gas may be converted to a liquid by an increase in pressure is termed the critical point and the variables are termed the critical temperature and the critical pressure of the gas. Sublimation is the changing of a solid directly to a gas.



Unstable situations such as super cooling and super heating arise when dealing with pure liquids. Super cooling is the cooling of a liquid to a temperature below its normal freezing point with no accompanying change in state. Super heating occurs when the boiling temperature is reached, but the liquid is not agitated by the liberation of vapor in its bulk. When either of these situations arise, when the change does start, it is very rapid and violent.

II. Illustration

Regulation (snowballs) or the melting of ice under pressure is a common example of this relationship of state to pressure and temperature. Boilers have been constructed which heat the water under a pressure greater than critical so that the steam is formed only at the turbine nozzle. (See also LeChatelier's Law).

III. References

1. Hodgman, Charles D., Handbook of Chemistry and Physics, 30th edition, Chemical Rubber Publishing Co., Cleveland, 1946. pp 1807-1809. Critical constant of gases.

2. Hausmann, Erick and Edgar P. Slack, Physics, D. Van Nostrand Co., Inc., New York, 1939. pp 259-261. Discussion of this change of state.

3. Mac Dougall, Frank H., Physical Chemistry, The Macmillan Co., New York, 1936. pp 361-366. Water, also reference for Clapeyron equation.

Quantities

Boiling Point
Equilibrium
Freezing Point
Gas
Material
Pressure
Temperature

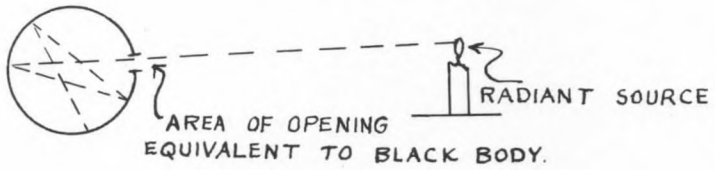
STEFAN-BOLTZMANN LAW (KIRCHHOFF'S LAW)

(Black Body Radiation)

I. Description

The Stefan-Boltzmann Law states that the total radiation from black body is proportional to the fourth power of its absolute temperature. A black body being defined as a body that absorbs all the radiant energy falling upon it.

Kirchhoff devised a scheme for making a practical and near perfect black body.



Kirchhoff also found that the relation between the powers of emission and the powers of absorption for rays of the same wave length is constant for all bodies at the same temperature.

1. A substance when excited by some means or other possesses a certain power of emission, to emit definite rays, whose wave lengths depend upon the nature of the substance and upon its temperature.

2. The substance exerts a definite absorptive power, which is a maximum for the rays it tends to emit.

3. At a given temperature the ratio between the emissive and the absorptive power for a given wave length is the same for all bodies and is equal to the emissive power of a perfectly black body.

II. Illustration

The effect of the law is used to determine temperature.

A furnace with a small opening in it is similar to Kirchhoff's sphere. The area of the small opening is effectively the black body. All the heat which passes through this area is absorbed. If an optical means were used to concentrate this radiant energy on a thermocouple junction, a millivoltmeter could be calibrated to give the temperature of that part of the furnace that the small opening sees.

III. Magnitude

The Stefan-Boltzmann law may be stated in mathematical form:

$$qb = .174 \times 10^{-4} A(T)^4$$

where: qb = total heat radiated from a black body, Btu/hr.
A = area of radiating surface (what units!)
T = absolute temperature of the black body, degree Rankine

Since black body conditions are not always present, the equation for total radiation may be modified with an emissivity factor for the particular material, surface condition and temperature.

IV. References

1. Richtmyer, F. K. and E. H. Kennard, Introduction to Modern Physics, McGraw-Hill Book Co., Inc., 1947, pp 149-152. The derivation of the Stefan-Boltzmann Law; pp 140-145, General discussion on radiation.

2. Koller, Lewis R., Ultraviolet Radiation, John Wiley & Sons, Inc., New York, 1952, pp 90-105. Stefan-Boltzmann Law and its relation to various light sources.

3. Zemansky, Mark W., Heat and Thermodynamics, McGraw-Hill Book Co., Inc., New York, 1943, pp 86-88. Description of Kirchhoff's Law and emissivity tables.

Quantities

Heat Flow
Radiation
Temperature
Wave Length
Area

STOKE'S LAW

I. Description

Stoke's Law is a derived expression for the force necessary to keep a small sphere moving at a uniform speed through a fluid. The basic equation (involving the force of gravity) is:

$$V_s = \frac{2ga^2}{9N} (\sigma - \rho)$$

where
- N = viscosity of medium, poises
- a = radius of particle
- σ = density of drop
- ρ = density of medium
- V_s = velocity of fall of spherical particle under gravity
- g = force of gravity

In order for the equation to hold, the following assumptions must be satisfied.

1. That the inhomogeneities in the medium are small in comparison with the size of the sphere.
2. That the sphere falls as it would in a medium of unlimited extent.
3. That the sphere is smooth and rigid.
4. That there is no slipping of the medium over the surface of the sphere.
5. That the velocity with which the sphere is moving is so small that the resistance to motion is all due to the viscosity of the medium and not its inertia.

II. Illustration

This law is very useful in the study of drops or other spherical particles falling in free air.

If a steel ball falling free in a tank of 80°F water what will the terminal velocity be?

$$V = \frac{2}{9}\frac{gr^2}{N}(C_1 - C_2)$$

$$= -4.31 \text{ cm/sec.}$$

where:
- g = 97.8 cm/sec^2
- r = .5 cm.
- C_1 = 7.85 dyne-sec^2/cm^4
- C_2 = 1.0 dyne-sec^2/cm^4
- N = 86.1 dyne sec/cm^2

This law was used by Millikan to measure ionic changes, hence the charge on an electron.

III. Magnitude of the Effect

The practical form of the equation is:

$$V_s = K'' \, S \, D^2 \, N^{-1} = K_3 \, S \, D^2$$

where:
- N = viscosity of gas, poises
- V = velocity, fpm
- D = dia. of particle, microns (.001 mm)
- S = specific gravity of particle
- K_3 = .0059 for spheres falling in normal air (1 atms), .0039 for irregular shapes.

This equation holds for streamline flow for diameters of 2 to 50 microns.

Viscosity of air at one atmosphere at 23°C is approximately .0001823 poises. For gases it increases with temperature; for liquids it decreases.

Typical size ranges of particles to which this equation is often applied are:

fog,	1 to 40 microns
pigments,	1 to 7 microns
fly ash,	3 to 70 microns
bacteria,	1 to 15 microns
pollens,	20 to 69 microns

IV. Reference

1. Page, Leigh, Introduction to Theoretical Physics, D. Van Nostrand Co., Inc., New York, 1935, pp 268-275. Mathematical derivation.

Quantities

Radius	Gas	Temperature	Viscosity
Density	Motion	Velocity, linear	

STOKE'S LAW ON FLUORESCENCE

I. Description

If a material is illuminated by radiation which it is capable of absorbing, the material may emit light. According to Stoke's Law, the wave length of the fluorescent, or emitted light, is always longer than the absorbed light. Since the atoms may already have energy, Stoke's Law does not strictly apply, but is applicable if the "center of gravity" of the fluorescent light is considered.

When light is emitted after the excitation is removed, the phenomena is termed phosphorescence, even though the mechanism for light production is the same.

II. Illustration

Fluorescent lamps which utilize the ultra-violet light produced by a low-pressure mercury discharge and then convert this energy to visible light are perhaps the most common example of fluorescence which illustrate the shift in wave length.

Fluorescent effects are usually demonstrated by light from a mercury arc filtered by a nickel oxide glass to remove visible light.

III. Magnitude

The ratio of light emitted to light absorbed is termed the fluorescence efficiency. Producing 30 lumens per watt, fluorescent lamps have about three times the efficiency of incandescent ones.

Some common fluorescent materials illustrate the frequency shift. All materials were illuminated by 3650 angstrom unit ultra-violet light.

Material	Fluorescence (not line emission)
Ethyl Acetate	blue (4900 A)
Fluorescin	blue green (5000 A)
Glycerine	purplish blue (4200 A)

Some laundry bleaches also fluoresce.

IV. References

1. Preston, Thomas, The Theory of Light, MacMillan & Co., Ltd., London, 1928, pp 518-521. Some fluorescing materials.

2. De Ment, Jack, Fluorescent Chemicals, Chemical Publishing Co., Inc., Brooklyn, N. Y., 1942. The book is useful as a summary of experimental fact.

Quantities

Wave Length
Frequency
Light, ultra-violet
Light, visible
Radiation

SURFACE TENSION

I. Description

Two fluids in contact exhibit phenomena, due to molecular attractions which appear to arise from a tension in the surface of separation. It may be expressed as dynes per cm or as ergs per square centimeter. Dimensions, - (mT^{-2}).

The total force along a line of length L on the surface of a liquid whose surface tension is T,

$$F = LT.$$

Capillary tubes. If a liquid of density d rises a height h in a tube of internal radius r the surface tension is,

$$T = \frac{rhdg}{2}$$

The tension will be in dynes per cm if r and h are in cm, d in grams per cm^3 and g in cm per sec^2. (Jurin's law is similar to this).

Drops and bubbles. Pressure in dynes per cm^2 due to surface tension on a drop of radium r cm for a liquid whose surface tension is T dynes per cm,

$$P = \frac{2T}{r}$$

For a bubble of mean radius r cm,

$$P = \frac{4T}{r}$$

II. Illustration

The rise of water in a small tube (capillary tube) is the result of the adhesive forces of glass for water which are greater than the cohesive forces of water. As the water is attracted by adhesion, the processes cause the water to rise. The water continues to rise until the upward pull of surface tension is equalized by the weight of liquid in the tube pulling down.

The height of the liquid is given by:

$$h = \frac{2T}{rdg}$$

where the units are defined as above.

III. Magnitude of the Effect

Water against air at 0°C - 75.6 dynes/cm.
10°C - 74.2 dynes/cm.
30°C - 71.2 dynes/cm.
100°C - 58.9 dynes/cm.

Benzene against Mercury at 20°C - 357 dynes/cm.

Water against Ethyl Ether at 20°C - 10.7 dynes/cm.

Water against Benzene at 20°C - 379 dynes/cm.

Mercury against air at 15°C - 787 dynes/cm.

IV. Reference

1. Hodgman, C. D., Handbook of Chemistry and Physics, Chemical Rubber Publishing Co., Cleveland, 1946, pp 1716-1727. Tables of values.

2. Mac Dougall, Frank H., Physical Chemistry, The Macmillan Co., New York, 1936, pp 90-97. Meniscus, capillary rise, bubbles, effect of temperature.

Quantities

Pressure
Surface Tension
Force
Radius

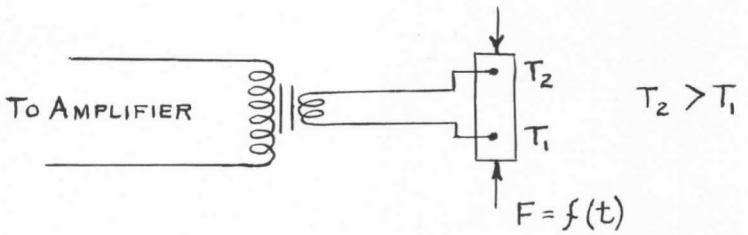
THERMOELASTIC EFFECT

I. Description

The thermoelastic effect (similar to the Thomson effect) is the production of an electrical potential between two points in a stressed metal when a constant temperature difference is maintained between the two points. The voltage produced varies both with the temperature difference and the stress intensity.

II. Illustration

Because thermoelectric currents are generated also, this method may be used only for varying stresses.



III. Magnitude

The voltage developed is of the same order of magnitude as the Thomson effect. The method has not, as yet, been used for applications requiring either high accuracy or sensitivity.

IV. Reference

1. Roberts, H. O., Mechanical Measurements by Electrical Means, The Instruments Publishing Co., Inc., Pittsburgh, 1946. p 188. Short discussion.

Quantities

Force
Strain & Stress
Temperature Gradient
Voltage

THERMOELECTRIC EFFECTS

A. SEEBECK EFFECT

I. Description

When a circuit consists of two different metals, and the two junctions of these metals are at different temperatures, there will be a flow of electric current in the circuit. This current is a function of the type of metals and is nearly proportional to the temperature differences between junctions and inversely proportional to the circuit resistance.

The Seebeck effect may be thought of as the result of two opposing effects: The Thomson emf due to the temperature gradient across the length of each conductor and the Peltier emf due to the difference in temperature of the two junctions.

II. Illustration

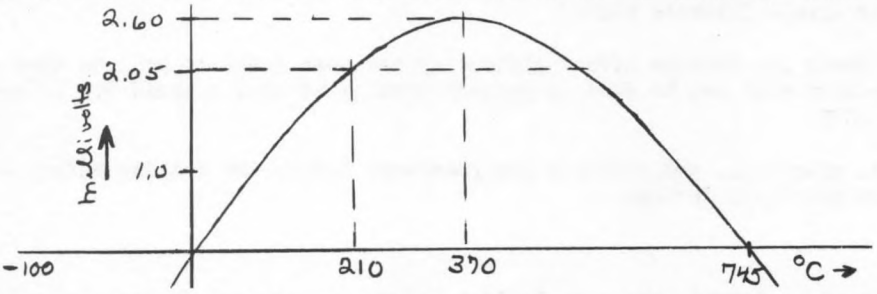
Thermocouples use this principle for measuring very wide range of temperatures.

III. Magnitude of the Effect

A Chromel-Alumel thermocouple develops approximately 20μV /° C difference in junction temperatures.

In the general case, when two metals are selected at random, the variation of emf with temperature is far from linear. The result is due to the combined effects described above.

If one junction of an iron-copper thermocouple is held at 0°C, the variation of emf developed by the thermocouple versus the temperature of the second junction is as follows:



This means that current would flow across the hot junction from iron to copper at any temperature between 0 and 745°C. Current would flow in the opposite direction at temperatures above or below this.

B. PELTIER EFFECT

I. Description

This is the inverse of the Seebeck Effect. When a current flows across the junction of two unlike metals, it gives rise to an absorption or liberation of heat. If the current flows in the same direction as the current at the hot junction of a thermoelectric circuit of the two metals, heat is absorbed; if it flows in the same direction as the current at the cold junction of the thermoelectric circuit, heat is liberated.

The heat developed in a junction of two metals is proportional to the first power of the current, and depends on the direction of the current.

The quantity of heat absorbed or liberated is given by the following equations:

$$\text{Rate heat is absorbed} = I\,T\,(dE/dt)$$

Where: I = current in amperes
T = absolute temperature (°K)

dE/dt = rate of change of thermo E M F with temperature.

II. Illustration

The Peltier Effect is an aspect of the thermoelectric effect and the magnitude is directly proportional to the thermoelectric power of the combination of the metals used, as well as the current through the junction.

The fundamental requirements for a Peltier couple are:

II. Illustration (Cont)

1. High contrasting thermoelectric power
2. Low heat conductivity
3. High electric conductivity

The useful Peltier cooling effect is less than total heat abstraction because of:

1. I^2R loss in the junction
2. I^2R loss in the materials
3. Heat from the surrounding medium
4. Conduction of heat from the hot junction

It is noted that two of the four factors depend upon the square of the current while the Peltier cooling is proportional to the first power of the current; therefore, for a given couple there is an optimum current for the maximum attainable cooling.

The cold junction cannot be made cooler by making the hot junction cooler, in fact, the cold junction will get warmer, because of the Thomson Effect.

The Peltier couple is used as a calibrated refrigerator in a radiation detector where current required to hold temperature constant is a measure of heat.

III. Magnitude of the Effect

A) At a junction of Fe - Ni at 0°C there would be liberated or absorbed 9.4×10^{-3} joules/second for each ampere of current. (This does not take into consideration any I^2R loss which would always liberate heat.)

B) In actual tests the Peltier Effect efficiency has been found to be less than one per cent. The best that can be done at present time is to cool a small bit of metal by not more than 10°C.

New alloys, materials, and concepts are necessary before the Peltier Effect can be utilized in practical devices.

IV. References

1. W. C. White, Some Experiments with Peltier Effect, Electrical Engineering, July 1951

2. T. F. Wall, The Peltier Effect, The Electrician, March 26, 1928

3. F. W. Sears, Principles of Physics, Addison-Wesley Press, Inc., 1944, Vol. 2, pp 160-168, Includes thermoelectric coefficients of metals and formulas for various emf's, the peak emf temperature, and the zero emf temperature.

4. Zemansky, Mark W., Heat and Thermodynamics, McGraw-Hill Book Co., Inc., New York, 1943, pp 266-273. Description of these effects and thermodynamic aspects.

5. Campbell, L. L., Galvanomagnetic & Thermomagnetic Effects, Longmans, Green & Co., N. Y., 1923. pp 258-269. Effect of magnetic field on thermoelectric effects.

Quantities

Heat Flow
Temperature
Thermal Conductivity
Resistance, electrical
Voltage

THOMSON & BENEDICK EFFECTS

I. Description

Both laws deal with the appearance and disappearance of heat in a heated conductor.

A. Thomson Effect - In unequally heated copper, heat is liberated at a point where the current and heat flow in the same direction and is absorbed when they flow in opposite directions. For copper, this tends to diminish the inequality of temperature, while for iron it tends to increase the difference.

B. Benedick Effect - This is the converse of the Thomson Effect. In a homogeneous conductor, a difference in potential between two points will produce a difference of temperature between these points.

For this effect, the difference in temperature between the ends of the rod is:

$$\Delta T = \frac{1}{\sigma} \int_{E_1}^{E^2} dE$$

where the limits of the integral are the voltages at either end of the rod and σ is the Thomson coefficient. In copper, the currents produced will tend to flow from the hot to the cold portions, while the action is reversed in iron. This effect is so very small that it is difficult to detect.

II. Illustration

These effects could be used to make small but accurate temperature differences. If a thin sheet of copper is suspended vertically between the poles of a horseshoe magnet and one corner of the sheet is heated, the copper will tend to rotate. Lead has no Thomson Effect.

III. Magnitude

The currents are small and the temperature gradients must be very sharp. The Thomson coefficient or specific heat of electricity is 1.0000 joule per coulomb per degree Centigrade.

IV. Reference

1. Harnwell, Gaylord P., Principles of Electricity and Electro-Magnetism, McGraw-Hill Book Co., Inc., New York, 1949, pp 203-205. A somewhat theoretical discussion of Thomson effect.

See also: Thermoelectric effects.

Quantities

Current
Direction
Heat Flow
Material
Temperature Gradient
Voltage

TOTAL REFLECTION

I. Description

When light travels so as to pass from one medium to another in which its velocity is greater, refraction ceases and total reflection begins at a certain critical angle of incidence θ such that

$$\sin \theta = \frac{1}{n}$$

where n is the index of the first medium with respect to the second. If the second medium is air n has the usual value for the first medium. For any other second medium,

$$n = \frac{n_1}{n_2}$$

where n_1 and n_2 are the indices of refraction for the first and second medium respectively.

II. Illustration

Perfectly reflecting mirrors may be made by this principle. Prisms used in binoculars use this technique. Bundles of light-transmitting fibres have been used to transmit image details to a remote position.

III. Magnitude

The angle for total reflection for some materials is:

Water	48° 27' 40"
Crown Glass	40° 30'
Lead Chromate	19° 28' 20"

IV. References

1. Hausmann, Erick and Edgar P. Slack, Physics, D. Van Nostrand Co., Inc., New York, 1939, pp 615-617. Description with examples.

2. Preston, Thomas, The Theory of Light, MacMillan & Co., Ltd., London, 1928, pp 99-100. Statement with examples, pp 152-155, Use to determine index of refraction.

Quantities

Angle, between two quantities
Angle, reflection
Angle, incidence
Light, visible
Index of Refraction
Material
Velocity of Light

TRIBOELECTRICITY

I. Description

There is produced an electromotive force between two dissimilar metals, both at the same temperature, by relative motion of the two materials. These materials may be liquid or solid.

II. Illustration

This effect has been known to cause difficulties in self-balancing systems, especially when subjected to vibration.

This phenomenon has been used in the design of a metals separator. Xerography, the process of making copies of printed pages and drawings, also depends to some extent on this process.

III. Magnitude of the Effect

The magnitude of the potentials depends upon the position of the metals in the electromotive series. Normally it may be expected to be 1 volt or less.

IV. References

1. Seth, J. B., B. Gulata and S. Singh, Electromotive Forces Between Two Metals in Relative Motion, Philosophical Magazine, Vol. 12, 1931, pp 409-429.

2. Gement, Andrew, Frictional Phenomena, Chemical Publishing Co., Brooklyn, N. Y., 1950, pp 457-460, Mechanism and magnitudes.

See also: Electrokinetic Phenomena.

Quantities

Charge
Friction
Material
Motion
Vibration
Voltage

VOLTA EFFECT

I. Description

When two metals are placed in contact with one another in the air, one becomes positive and the other negative, though the changes are feeble.

II. Illustration

Rectifiers (such as the copper oxide) take advantage of this contact potential. Dry voltic piles have been employed to produce high voltages for very low current applications such as focusing electrodes for infra-red image converter tubes.

III. Magnitude of the Effect

If the two metals are iron and copper, the iron has a potential about 0.15 volts higher than the copper; while for tin and iron the difference is 0.31 volts, the tin being the higher. For tin and copper (above) it is 0.31 volts $\neq$ 0.15 volts = 0.46 volts; it makes no difference whether the tin and copper are in direct contact, or separated by other intervening metals. The effect is temperature sensitive.

IV. References

1. Elliott, A., The Dry Voltic Pile, Electronic Engineering, October, 1948, Vol. 20, No. 248, London, pp 317-319. A description of a practical 500 volt pile.

Quantities

Temperature
Rectification
Material
Voltage

Psychology
Acoustics
Optics

WEBER - FECHNER LAW

I. Description

The Weber - Fechner law of psychology states that the least change in the stimulus necessary to produce a preceptible change in response is proportional to the stimulus already existing.

II. Illustration

This law forms the basis of the power level measurement used in audio systems. Since the ear finds that changes in sound intensity are in the same ratio as their energies, a change from 20 to 30 milliwatts of acoustic energy will seem to be the same increment as a change from 200 to 300 milliwatts of audio power. These levels are equally spaced on a logarithmic scale. The unit is the decibel, and the gain or loss of a system is given by:

$$\text{Number of decibels} \quad db = 10 \log \frac{P_1}{P_2}$$

Where: P_1 and P_2 are the input and output power levels of the system.

III. Magnitude

All the senses follow this law. The approximate minimum changes discernible are:

Light	1%
Length of lines	2%
Feeling of weight	10%
Sound loudness	30%

IV. References

1. Ware, L. A. and H. R. Reed, Communication Circuits, John Wiley & Sons, Inc., 2nd edition, New York. p 46. Decibels.

2. Woodworth, Robert S, Psychology, Henry Holt & Co., New York, 1929, pp 409-412. Errors of perception.

Quantities

Energy
Force
Temperature
Power
Sound
Stimulus
Noise

WIEDEMANN - FRANZ'S LAW

I. Description

The ratio of the thermal to the electrical conductivity for all metals is proportional to the absolute temperature T, and in calories - ohm per second per degree equal to 5.345×10^{-9} T. For 0°C (273° absolute) this gives 0.00000146 calories - ohm per second per degree. The Wiedemann - Franz formula is theoretical and its coefficient involves both the Boltzmann constant and the electronic charge. Lorenz showed that this constant varies with absolute temperature.

II. Illustration

While at very low temperatures the thermal conductivity of metals increases, so does the electrical conductivity. However, these two phenomena do not follow parallel paths and their ratio does change. Variations in this ratio may be shown by reference to some thermal conductivities (calories/sec. cm °C) for cm thickness for several poor conductors.

Rock Salt	.0137
Quartz	.0263 (perpendicular to the axis)
Bismuth	.0194

III. Magnitude of the Effect

The ratio observed for a number of metals

Platinum	0.00000143	calories	ohm	per	second	per	degree
Copper	0.00000156	"	"	"	"	"	"
Lead	0.00000169	"	"	"	"	"	"

For most metals the observed ratio is a little higher than that given by the formula, doubtless because of thermal conduction due to other causes than electronic activity.[1]

IV. Reference

1. Kraus, Charles A., The Properties of Electrically Conducting Systems, The Chemical Catalog Company, Inc., N. Y., 1922, pp 402-4. A short discussion.

Quantities

Heat Flow
Material
Resistance, electrical
Temperature
Thermal Conductivity

WIEN EFFECT

I. Description

The equivalent conductance* of an electrolyte increases with the applied voltage. This means that Ohms Law is invalid for electrolytic solutions. This effect is especially pronounced for the weak organic acids, the weaker the acid, the stronger the effect.

II. Illustration

The Debye & Onsager theory of conductance* explains the Wien effect by the faster ion speeds of 1 meter/sec. at high voltages versus 0.001 cm/sec. at low voltages. The conductance of the solution will approach a theoretical maximum value at high voltages. This theoretical value is attained at lower voltages for lower concentrations. The Blumentritt equation expresses the Wien effect for voltage gradients up to 30,000 v./cm:

$$\Delta \Lambda = a E^2 - b E^4$$

Where: Λ = equivalent conductance*
a, b = constants
E = applied voltage

III. Magnitude

The constants for the Blumentritt equation have been observed for a number of materials:

Salt	Normality Moles/Liter	a x 10^{11}	b x 10^{11}	Normality Moles/Liter	a x 10^{11}	b x 10^{11}
$MgSO_4$	.00605	1.49	1.7	.00127	2.5	6.0
$MgCrO_4$	.00574	1.21	3.0	.00126	1.8	7.5
$K_3Fe(CN)_6$	.00350	.44	1.1	.00082	.77	3.4
$K_4Fe(CN)_6$	.00363	.88	2.3	.00083	.82	3.8
$Ba_2Fe(CN)_6$	.00575	6.6	3.2	.00108	11.6	6.9

IV. Reference

1. Dole, Malcolm, Principles of Experimental and Theoretical Electro-Chemistry, McGraw-Hill Book Co., Inc., New York, 1935, pp 108-128. Effect, cause and calculation of magnitude.

See also: Kohlrausch's Law.

*Defined in Kohlrausch's Law.

Quantities

Concentration
Current
Material
Resistance, electrical
Solutions
Voltage

WIEN'S DISPLACEMENT LAW

I. Description

A) When the temperature of a radiating black body increases, the wave length corresponding to maximum energy decreases so that the product of the absolute temperature and wave length is constant.

$$\lambda_{max}\, T = C_1$$

B) The emissive power of the black body within the maximum intensity wave length interval $d\lambda$ is proportional to the fifth power of the absolute temperature;

$$dE_{max} = C_2\, T^5\, d\lambda$$

c) The distribution of radiation intensity is

$$\Psi_\lambda = C_1 \lambda^{-5}\, e^{-\frac{C_2}{\lambda T}}$$ where C_1 & C_2 are constants

II. Illustration

As the temperature rises the peak of the distribution curve is displaced or shifted toward the short wave length end of the spectrum. This can be observed when heating an iron rod, it glows dull red first, then gets white hot as its temperature rises.

III. Magnitude of the Effect

The value of the "displacement constant" C_1 is about 0.2884 centimeter degree differing slightly on the method of computation used.

The value of C_2 is about 1.302×10^{-4} erg/cm^3 sec degree^5 as established by Planck.

IV. Reference

1. Richtmyer, F. K. and E. H. Kennard, Introduction to Modern Physics, McGraw-Hill Book Company, Inc., New York, 1947, pp 157-8. Derivation of the law. Also p 183 for differences in the value of C_1.

See also: Stefan-Boltzmann Law.

Quantities

Light, visible
Radiation
Temperature
Wave Length
Frequency

Atomic Physics
Optics
Electricity & Magnetism

WOOD & ELLETT EFFECT (1923)

I. Description

The almost complete plane polarization of the resonance radiation of mercury vapor for the 2537 Å line is completely removed by the action of weak magnetic fields. For both mercury and sodium vapor, magnetic fields may destroy polarization if initially present, and produce it if it is initially absent.

II. Illustration

For mercury vapor, this effect is observable only when the vapor pressure is low so as to suppress the unpolarized resonance radiation. The relation of the directions of the magnetic field, plane of incident light polarization and the plane of viewing is important, in that the angles between them determine the plane of polarization of the observed light, or even whether it will be polarized at all.

III. Magnitude

Magnetic fields of as low an intensity as that of the earth are sufficient to destroy polarization in mercury vapor, although the maximum effect occurs for intensities of 2-3 gauss for mercury and 80-100 gauss for sodium. For alternating magnetic field, this depolarizing action decreases with increasing frequency, disappearing at about 5 m.c.

IV. Reference

1. Wood, Robert W., Physical Optics, The Macmillan Co., N. Y., 1934. pp 718-728. Effect, cause and related magneto-optical effects.

Quantities

Light, visible
Light, ultraviolet
Frequency
Magnetic Flux
Polarization, optical
Radiation

Atomic Physics
Electricity & Magnetism
Optics

*ZEEMAN EFFECT

I. Description

When a source having a strong line spectra is placed in a strong magnetic field, the lines of the spectrum are widened and many spectral lines may be broken into multiple lines.

The edges of the broadened line show traces of circular or plane polarization depending on whether the observation is made along or at right angles to the lines of magnetic force.

When the light is examined in a direction perpendicular to the lines of force, the edges are found to be plane-polarized. With a sufficiently strong field the line will appear triple. The two outer components are polarized with their vibration directions perpendicular to the lines of force. The pattern changes with strong and weak field, the change being known as the Paschen-Bock Effect.

II. Illustration

When a source of light, such as a metallic arc, is placed between the poles of a powerful electromagnet, the lines of its spectrum are split into components, some displaced to the red and some to the blue and each of these two is polarized in a characteristic way. This is a means of discovering the nature of the forces in the atom.

III. Magnitude of the Effect

In a magnetic field of 30,000 gauss, the extreme components into which a line is split are never more than about one angstrom unit apart, and there may be more than a dozen components between them, so that it is not only necessary to have a powerful magnet but also a spectroscope of high resolving power.

IV. Reference

1. Richtmyer, F. K. and E. H. Kennard, Introduction to Modern Physics, McGraw-Hill Book Co., Inc., New York, 1947, pp 75-80. Effect and explanation. pp 365-386, Normal and anomalous effect, strong and weak fields.

*Also called:

Lorentz-Thomson-Zeeman Effect
Paschen-Bock Effect

Quantities

Color
Frequency
Light, visible
Magnetic Flux
Wave Length

CROSS REFERENCE BY FIELDS OF SCIENCE

ACOUSTICS

Caviation
Diffraction
Doppler (Fizeau) Effect
Interference
Magnetic Dispersion of Sound
Organ Pipe Resonance
Weber - Fechner Law

ATOMIC PHYSICS

Absorption
Boltzmann Distribution Law
Briet-Wagner Theory
Bremstrahlung Radiation
Compton Effect
Constant Heat Capacity Law
Cosmic Rays
Diffraction
Fission
Geiger Nutall Rule
Group Displacement Law
Photoelectric Effect
Quantum Theory
Radiation Pressure
Radioactivity
Richardson's Effect (Edison Effect)
Schrodinger's Wave Equation
Stark Effect
Stefan-Boltzmann Law (Kirchhoff's Law)
Stoke's Law on Fluorescence
Wiedemann-Franz's Law
Wien's Displacement Law
Wood & Ellett Effect, or Resonance Radiation
Zeeman Effect

CHEMISTRY (AND PHYSICAL CHEMISTRY)

Absorption
Adsorption
Arrhenius Theory of Electrolytic Dissociation
Brownian Movement
Debye Frequency Effect
Electrocapillarity
Electrokinetic Phenomena
Faraday's Law of Electrolysis
Fick's Law
Gibbs Theory of Equilibria
Graham's Law
Henry's Law
Ideal Gas Laws
Joule-Thompson Effect or Joule-Kelvin Effect
Kohlrausch's Law
Le Chatelier's Law
Periodic Law (or Table)
Raoult's Law
Snell's Law, The Law of Refraction
State and Change of State
Surface Tension
Volta Effect
Wien Effect

ELECTRICITY & MAGNETISM

Ampere's Law
Ampere's (Biot-Savart) Law
Barkhausen Effect
Capacity/Dielectric
Corbino Effect
Coulomb's Law
Curie-Weiss Law
Debye Frequency Effect
Electrocapillarity
Electrokinetic Phenomena
Faraday Effect (Magneto-Optical Rotation)
Faraday's Law of Electrolysis
Faraday's Law of Induction
Ferranti Effect
Galvano-Magnetic and Thermo-Magnetic Effects
Gauss' Law
Impedance/Frequency
Johnson-Rahbeck and/or Winslow Effect
Joule's Law
Kerr Effect (Electrostatic)
Kerr Magneto-Optic Effect
Kirchhoff's Laws
Kohlrausch's Law
Magnetic Behavior of Materials
Magnetic Effects
Magnetic Dispersion of Sound
Magnetic Susceptance (Gauss Effect)
Magnetostriction and Allied Effects
Ohms Law
Paschen's Law
Photoelectric Effect
Photomagnetic Effect
Piezoelectric Effect
Pinch Effect
Proximity Effect
Pyroelectric Effect
Residual Voltages
Resistance/Dimension
Resistance/Temperature
Richardson's Effect (Edison Effect)
Schrodinger's Wave Equation
Shot Effect
Skin Effect
Thermoelastic Effect
Thermoelectric Effects
Thomson & Benedick Effects
Triboelectricity
Volta Effect
Wiedemann-Franz's Law
Wien Effect
Wood & Ellett Effect or Resonance Radiation
Zeeman Effect

FLUID MECHANICS

Archimedes' Principle
Bernoulli Theorem
Cavitation
Electrocapillarity
Electrokinetic Phenomena
Graham's Law
Henry's Law
Ideal Gas Laws
Joule-Thomson Effect or Joule-Kelvin Effect
Kelvin's Principle for Fluid Drops
Stoke's Law
Surface Tension

GENERAL PHYSICS

Adsorption
Archimedes' Principle
Bauschinger Effect
Bernoulli Theorem
Brownian Movement
Constant Heat Capacity Law
Electrocapillarity
Eotvos Effect
Expansion/Temperature or Thermal Expansion
Hooke's Law
Ideal Gas Laws
Joule-Thomson Effect or Joule-Kelvin Effect
Kelvin's Principle for Fluid Drops
Kepler's Laws
Lambert's Law, Absorption Coefficient
Le Chatelier's Law
Newton's Laws
Periodic Law (or Table)
Snell's Law, The Law of Refraction
State and Change of State
Stoke's Law

MECHANICS

Bauschinger Effect
Coulomb's Law
Elastic Limit
Hooke's Law
Johnson-Rahbek and/or Winslow Effect
Magnetic Dispersion of Sound
Newton's Laws
Piezoelectric Effect
Poisson's Coefficient (or ratio)
Resistance/Dimension
Thermoelastic Effect
Triboelectricity

OPTICS

Absorption
Brewster's Law
Christiansen Effect
Diffraction
Doppler (Fizeau) Effect
Faraday Effect (Magneto-Optical Rotation)
Gladstone and Dale's Law
Interference
Kerr Effect (Electrostatic)
Kerr Magneto-Optic Effect
Lambert's Law, Absorption Coefficient
Optical Rotary Power
Purkinje Effect
Radiation Pressure
Snell's Law - The Law of Refraction
Stoke's Law on Fluorescence
Total Reflection
Weber-Fechner Law
Wood and Ellett Effect or Resonance Radiation
Zeeman Effect

PSYCHOLOGY

Purkinje Effect
Weber-Fechner Law

CROSS REFERENCE BY PHYSICAL QUANTITIES

ACCELERATION
- Bremstrahlung Radiation (Acceleration, Density, Electric Field, Energy, Frequency, Radiation, Voltage, X-rays)
- Electro-kinetic Phenomena (Acceleration, Current, Flow, Pressure, Voltage)
- Kepler's Laws (Acceleration, Area, Force, Time, Length, Motion)
- Newton's Laws (Acceleration, Direction, Equilibrium, Force, Mass, Motion)

ALTITUDE
- Bernoulli Theorem (Altitude, Pressure, Density, Velocity, Flow)
- Cosmic Rays (Geographical Position, Altitude, Incidence Angle, Concentration, Direction, Energy, Radiation)

ANGLES (BETWEEN TWO QUANTITIES)
- Ampere's Law (Force, Current, Length of Conductor, Magnetic Flux, Charge, Velocity, Angle, Voltage)
- Ampere's (Biot-Savart) Law (1820) (Magnetic Field, Current, Length of Conductor, Linear Displacement, Angle)
- Faraday Effect (Magneto-Optical Rotation) (Magnetic Flux, Angular Displacement, Length, Angle between Two Quantities, Index of Refraction, Polarization, Temperature, Frequency, Wave Length, Visible Light)
- Galvano-Magnetic & Thermo-Magnetic Effects (Current, Magnetic Flux, Temperature, Angle between Two Quantities, Material, Heat Flow)
- Total Reflection (Angle between Two Quantities, Angle of Reflection, Angle of Incidence, Visible Light, Index of Refraction, Material, Velocity of Light)

ANGLE, INCIDENCE
- Cosmic Rays (Geographical Position, Altitude, Incidence Angle, Concentration, Direction, Energy, Radiation)
- Snell's Law - 1621, The Law of Refraction (Angle of Incidence, Angle of Refraction, Visible Light, Wave Length, Density, Molecular Weights, Molecules, Temperature, Velocity of Light)
- Total Reflection (Angle between Two Quantities, Angle of Reflection, Angle of Incidence, Visible Light, Index of Refraction, Material, Velocity of Light)

ANGLE, REFLECTION
- Brewster's Law (Refraction Angle, Polarization, Reflection Angle, Wave Length, Frequency)
- Diffraction (Reflection Angle, Wave Length, Linear Displacement, X-rays, Color, Frequency, Visible Light, Radiation, Sound)
- Total Reflection (Angle between Two Quantities, Angle of Reflection, Angle of Incidence, Visible Light, Index of Refraction, Material, Velocity of Light)

ANGLE, REFRACTION
- Brewster's Law (Refraction Angle, Polarization, Reflection Angle, Wave Length, Frequency)
- Gladstone & Dale's Law (Refraction Angle, Color, Density, Index of Refraction, Material, Velocity of Light, Wave Length)
- Snell's Law - 1621, The Law of Refraction (Angle of Incidence, Angle of Refraction, Index of Refraction, Visible Light, Wave Length, Density, Molecular Weights, Molecules, Temperature, Velocity of Light)

AREA
- Fick's Law (Solutions, Time, Temperature, Area, Concentration, Voltage)
- Gauss Law (Electric Field, Area, Charge)
- Hooke's Law 1878 (Force, Area, Length, Strain & Stress)
- Kepler's Laws (Acceleration, Area, Force, Time, Length, Motion)
- Pinch Effect (Area, Current, Force, Pressure, Electrical Resistance, Temperature)
- Richardson's Effect (Edison Effect) (Current, Temperature, Area, Material)
- Stefan-Boltzmann Law (Kirchhoff's Law) (Heat Flow, Radiation, Temperature, Wave Length, Area)

ATOMIC WEIGHT
- Constant Heat Capacity Law (Atomic Weight, Specific Heat)
- Fission (Atomic Weight, Energy, Radiation)
- Group Displacement Law (Atomic Weight, Charge, Energy, Radiation, Time, X-rays)
- Periodic Law (or Table) - 1869 (Atomic Weight, Material, Radiation)

BOILING POINT

Arrhenius Theory of Electrolytic Dissociation (Solvent, Solute, Freezing Point, Boiling Point)
Raoult's Law (Concentration, Gas, Molecular Weight, Partial Pressure, Solutions, Vapor Pressure, Boiling Point, Freezing Point)
State and Change of State (Boiling Point, Equilibrium, Freezing Point, Gas, Material, Pressure, Temperature)

CAPACITY AND CAPACITANCE

Adsorption (Concentration, Capacity, Gas, Material, Molecules, Surface Tension)
Impedance/Frequency (Inductance, Capacity, Frequency, Impedance)
Capacity/Dielectric (Charge, Capacitance, Voltage, Dielectric Constant, Linear Displacement, Temperature, Thickness)

CHARGE

Ampere's Law (Force, Current, Length of Conductor, Magnetic Flux, Charge, Velocity, Angle, Voltage)
Capacity/Dielectric (Charge, Capacitance, Voltage, Dielectric Constant, Linear Displacement, Temperature, Thickness)
Coulomb's Law (Force, Charge, Linear Displacement, Dielectric Constant, Magnetic Flux)
Gauss Law (Electric Field, Area, Charge)
Group Displacement Law (Atomic Weight, Charge, Energy, Radiation, Time, X-rays)
Hertz Effect (Wiedemann & Ebert) - 1887 (Visible Light, Ultraviolet Light, Charge, Radiation)
Pyroelectric Effect (Charge, Electric Field, Heat Flow, Temperature, Temperature Gradient)
Piezoelectric Effect (Charge, Force, Voltage, Vibration, Energy)
Radioactivity (Charge, Energy, Radiation, X-rays)
Residual Voltage (Charge, Current, Voltage, Time)
Triboelectricity (Charge, Friction, Material, Motion, Vibration, Voltage)

COLOR

Absorption (Color, Frequency, Visible Light, Radiation, Wave Length, Material)
Christiansen Effect (Wave Length, Temperature, Color, Visible Light)
Diffraction (Wave Length, Reflection Angle, Linear Displacement, X-rays, Color, Frequency, Visible Light, Radiation, Sound)
Gladstone & Dale's Law (Refraction Angle, Color, Density, Index of Refraction, Material, Velocity of Light, Wave Length)
Kerr Magneto-Optic Effect (Magnetic Flux Color, Visible Light, Material, Polarization)
Purkinje Effect (Color, Energy, Visible Light, Stimulus)
Zeeman Effect (Color, Frequency, Visible Light, Magnetic Flux, Wave Length)

CONCENTRATION

Adsorption (Concentration, Capacity, Gas, Material, Molecules, Surface Tension)
Cosmic Rays (Geographical Position, Altitude, Incidence Angle, Concentration, Direction, Energy, Radiation)
Debye Frequency Effect (Concentration, Current, Frequency, Material, Resistance-Electrical, Solution, Electrolysis)
Fick's Law (Solutions, Time, Temperature, Area, Concentration, Voltage)
Gibbs Theory of Equilibria - Phase Rule (Pressure, Temperature, Concentration)
Graham's Law (Molecular Weight, Temperature, Concentration, Flow, Gas, Osmosis, Pressure, Solutions, Time)
Kohlrausch's Law (Concentration, Current, Dielectric Constant, Material, Electrical Resistance, Solutions, Temperature)
Le Chatelier's Law (Concentration, Equilibrium, Pressure, Temperature)
Optical Rotary Power (Length, Material, Solution, Concentration, Wave Length, Temperature, Polarization)
Raoult's Law (Concentration, Gas, Molecular Weight, Partial Pressure, Solutions, Vapor Pressure, Boiling Point, Freezing Point)
Wien Effect (Concentration, Current, Material, Electrical Resistance, Solutions, Voltage)

CURRENT

Ampere's Law (Force, Current, Length of Conductor, Magnetic Flux, Charge, Velocity, Angle, Voltage)
Ampere's (Biot-Savart) Law (1820) (Magnetic Field, Current, Length of Conductor, Linear Displacement, Angle)
Corbino Effect (Current, Length, Magnetic Flux, Material)
Debye Frequency Effect (Concentration, Current, Frequency, Material, Resistance - electrical, Solution, Electrolysis)
Electro-kinetic Phenomena (Acceleration, Current, Flow, Pressure, Voltage)
Faraday's Law of Electrolysis 1833 (Weight, Current, Material, Electrolysis)

CURRENT (CONT)

Faraday's Law of Induction (Voltage, Magnetic Flux, Angular Velocity, Time, Current, Energy, Equilibrium)
Galvano-Magnetic & Thermo-Magnetic Effects (Current, Magnetic Flux, Temperature, Angle between Two Quantities, Material, Heat Flow)
Joule's Law (Resistance, Current, Time, Energy)
Kirchhoff's Laws (Current, Voltage)
Kohlrausch's Law (Concentration, Current, Dielectric Constant, Material, Electrical Resistance, Solutions, Temperature)
Magnetic Dispersion of Sound (Current, Density, Frequency, Material, Motion, Permeability, Electrical Resistance, Thickness, Velocity of Sound, Vibration, Sound)
Ohms Law (Current, Electrical Resistance, Voltage)
Photomagnetic Effect (Current, Magnetic Flux, Permeability, Radiation, Visible Light, Temperature, Voltage)
Pinch Effect (Area, Current, Force, Pressure, Electrical Resistance, Temperature)
Proximity Effect (Current, Electric Field, Radius, Resistance)
Residual Voltage (Charge, Current, Voltage, Time)
Richardson's Effect (Current, Temperature, Material, Area)
Shot Effect (Current, Motion, Noise, Sound, Temperature, Voltage)
Skin Effect (Inductance, Current, Material, Permeability, Electrical Resistance, Temperature)
Thomson & Benedick Effects (Current, Direction, Heat Flow, Material, Temperature Gradient, Voltage)
Wien Effect (Concentration, Current, Material, Electrical Resistance, Solutions, Voltage)

DENSITY

Archimedes' Principle (287-212 BC) (Density, Specific Gravity, Volume, Mass)
Bernoulli Theorem (Altitude, Pressure, Density, Velocity, Flow)
Bremstrahlung Radiation (Acceleration, Density, Electric Field, Energy, Frequency, Radiation, Voltage, X-rays)
Gladstone & Dale's Law (Refraction Angle, Color, Density, Index of Refraction, Material, Velocity of Light, Wave Length)
Kelvin's Principle for Fluid Drops (Density, Equilibrium, Radius, Surface Tension, Temperature, Vapor Pressure)
Magnetic Dispersion of Sound (Current, Density, Frequency, Material, Motion, Permeability, Electrical Resistance, Thickness, Velocity of Sound, Vibration, Sound)
Snell's Law - 1621, The Law of Refraction (Angle of Incidence, Angle of Refraction, Index of Refraction, Visible Light, Wave Length, Density, Molecular Weights, Molecules, Temperature, Velocity of Light)
Stoke's Law (Radius, Density, Gas, Motion, Temperature, Linear Velocity, Viscosity)

DIELECTRIC CONSTANT

Capacity/Dielectric (Charge, Capacitance, Voltage, Dielectric Constant, Linear Displacement, Temperature, Thickness)
Coulomb's Law (Force, Charge, Linear Displacement, Dielectric Constant, Magnetic Flux)
Kohlrausch's Law (Concentration, Current, Dielectric Constant, Material, Electrical Resistance, Solutions, Temperature)

DIRECTION

Cosmic Rays (Geographical Position, Altitude, Incidence Angle, Concentration, Direction, Energy, Radiation)
Newton's Laws (Acceleration, Direction, Equilibrium, Force, Mass, Motion)
Thomson & Benedick Effects (Current, Direction, Heat Flow, Material, Temperature gradient, Voltage)

DISPLACEMENT, ANGULAR

Faraday Effect (Magneto-Optical Rotation) (Magnetic Flux, Angular Displacement, Length, Angle between Two Quantities, Index of Refraction, Polarization, Temperature, Frequency, Wave Length, Visible Light)
Magnetostriction & Allied Effects (Force, Frequency, Material, Sound, Magnetic Flux, Length, Angular Displacement)

DISPLACEMENT, LINEAR

Ampere (Biot-Savart) Law (1820) (Magnetic Field, Current, Length of Conductor, Linear Displacement, Angle)
Bauschinger Effect (Linear Displacement, Elastic Limit, Force, Stress and Strain, Temperature)
Capacity/Dielectric (Charge, Capacitance, Voltage, Dielectric Constant, Linear Displacement, Temperature, Thickness)
Coulomb's Law (Force, Charge, Linear Displacement, Dielectric Constant, Magnetic Flux)

DISPLACEMENT, LINEAR (CONT)
- Diffraction (Wave Length, Reflection Angle, Linear Displacement, X-rays, Color, Frequency, Visible Light, Radiation, Sound)
- Expansion/Temperature or Thermal Expansion (Length, Linear Displacement, Temperature, Volume)
- Poisson's Coefficient (or Ratio) (Linear displacement, Force, Length, Volume)
- Schrodinger's Wave Equation (Linear Displacement, Energy, Frequency, Mass, Motion, Time, Wave Length)

ELASTIC LIMIT
- Bauschinger Effect (Linear Displacement, Elastic Limit, Force, Strain and Stress, Temperature)
- Elastic Limit (Strain and Stress, Material)

ELECTRIC FIELD
- Bremstrahlung Radiation (Acceleration, Density, Electric Field, Energy, Frequency, Radiation, Voltage, X-rays)
- Gauss Law (Electric Field, Area, Charge)
- Kerr Effect - Electrostatic (Polarization, Electric Field, Visible Light, Material, Time)
- Proximity Effect (Current, Electric Field, Radius, Electrical Resistance)
- Pyroelectric Effect (Charge, Electric Field, Heat Flow, Temperature, Temperature Gradient)
- Stark Effect (Electric Field, Material, Voltage, Wave Length)

ELECTROLYSIS
- Debye Frequency Effect (Concentration, Current, Frequency, Material, Resistance - electrical, Solution, Electrolysis)
- Faraday's Law of Electrolysis - 1833 (Weight, Current, Material, Electrolysis)

ENERGY
- Boltzmann Distribution Law (Energy, Radiation, Temperature)
- Bremstrahlung Radiation (Acceleration, Density, Electric Field, Energy, Frequency, Radiation, Voltage, X-rays)
- Breit-Wagner Theory (Energy, Velocity-linear)
- Cavitation (Energy, Motion, Pressure, Temperature, Vapor Pressure, Vibration, Sound)
- Cosmic Rays (Geographical Position, Altitude, Incidence Angle, Concentration, Direction, Energy, Radiation)
- Faraday's Law of Induction (Voltage, Magnetic Flux, Angular Velocity, Time, Current, Energy, Equilibrium)
- Fission (Atomic Weight, Energy, Radiation)
- Geiger-Nutall Rule (Energy, Linear Velocity, Length)
- Group Displacement Law (Atomic Weight, Charge, Energy, Radiation, Time, X-ray)
- Joule's Law (Resistance, Current, Time, Energy)
- Lambert's Law, Absorption Coefficient (Energy, Visible Light, Radiation, Thickness, X-rays, Solutions, Material)
- Photoelectric Effect (Energy, Material, Frequency, Velocity)
- Purkinje Effect (Color, Energy, Visible Light, Stimulus)
- Piezoelectric Effect (Charge, Force, Voltage, Vibration, Energy)
- Quantum Theory - 1900 (Energy, Frequency, Radiation, Velocity of Light, Wave Length)
- Radioactivity (Charge, Energy, Radiation, X-rays)
- Schrodinger's Wave Equation (Linear Displacement, Energy, Frequency, Mass, Motion, Time, Wave Length)
- Weber-Fechner Law (Energy, Force, Temperature, Power, Sound, Stimulus, Noise)

EQUILIBRIUM
- Faraday's Law of Induction (Voltage, Magnetic Flux, Angular Velocity, Time, Current, Energy, Equilibrium)
- Kelvin's Principle for Fluid Drops (Density, Equilibrium, Radius, Surface Tension, Temperature, Vapor Pressure)
- Le Chatelier's Law (Concentration, Equilibrium, Pressure, Temperature)
- Newton's Laws (Acceleration, Direction, Equilibrium, Force, Mass, Motion)
- State & Change of State (Boiling Point, Equilibrium, Freezing Point, Gas, Material, Pressure, Temperature)

FLOW
- Bernoulli Theorem (Altitude, Pressure, Density, Velocity, Flow)
- Electrocapillarity (Pressure, Voltage, Surface Tension, Flow)
- Electro-kinetic Phenomena (Acceleration, Current, Flow, Pressure, Voltage)
- Graham's Law (Molecular Weight, Temperature, Concentration, Flow, Gas, Osmosis, Pressure, Solutions, Time)

FORCE

Ampere's Law (Force, Current, Length of Conductor, Magnetic Flux, Charge, Velocity, Angle, Voltage)
Bauschinger Effect (Linear Displacement, Elastic Limit, Force, Stress and Strain, Temperature)
Coulomb's Law (Force, Charge, Linear Displacement, Dielectric Constant, Magnetic Flux)
Hooke's Law 1678 - (Force, Area, Length, Strain and Stress)
Johnsen-Rahbek and/or Winslow Effect (Friction, Force, Material, Voltage)
Kepler's Laws (Acceleration, Area, Force, Time, Length, Motion)
Magnetostriction and Allied Effects (Force, Frequency, Material, Sound, Magnetic Flux, Length, Angular Displacement)
Newton's Laws (Acceleration, Direction, Equilibrium, Force, Mass, Motion)
Pinch Effect (Area, Current, Force, Pressure, Electrical Resistance, Temperature)
Poisson's Coefficient (or Ratio) (Linear Displacement, Length, Force, Volume)
Piezoelectric Effect (Force, Energy, Voltage, Vibration, Charge)
Surface Tension (Pressure, Surface Tension, Force, Radius)
Thermoelastic Effect (Force, Strain and Stress, Temperature Gradient, Voltage)
Weber-Fechner Law (Energy, Force, Temperature, Power, Sound, Stimulus, Noise)

FREEZING POINT

Arrhenius Theory of Electrolytic Dissociation (Solute, Solvent, Freezing Point, Boiling Point)
Raoult's Law (Concentration, Gas, Molecular Weight, Partial Pressure, Solutions, Vapor Pressure, Boiling Point, Freezing Point)
State & Change of State (Boiling Point, Equilibrium, Freezing Point, Gas, Material, Pressure, Temperature)

FREQUENCY

Absorption (Color, Frequency, Visible Light, Radiation, Wave Length, Material)
Bremstrahlung Radiation (Acceleration, Density, Electric Field, Energy, Frequency, Radiation, Voltage, X-rays)
Brewster's Law (Refraction Angle, Polarization, Reflection Angle, Wave Length, Frequency)
Debye Frequency Effect (Concentration, Current, Frequency, Material, Resistance-electrical, Solution, Electrolysis)
Diffraction (Wave Length, Reflection Angle, Linear Displacement, X-rays, Color, Frequency, Visible Light, Radiation, Sound)
Doppler-(Fizeau) Effect 1842 (Frequency, Visible Light, Motion, Radiation, Linear Velocity, Wave Length, Sound)
Faraday Effect (Magneto-Optical Rotation) (Magnetic Flux, Angular Displacement, Length, Angle between Two Quantities, Index of Refraction, Polarization, Temperature, Frequency, Wave Length, Visible Light)
Ferranti Effect (Voltage, Frequency, Length)
Impedance/Frequency (Inductance, Capacity, Frequency, Impedance)
Magnetic Dispersion of Sound (Current, Density, Frequency, Material, Motion, Permeability, Electrical Resistance, Thickness, Velocity of Sound, Vibration, Sound)
Magnetostriction and Allied Effects (Force, Frequency, Material, Sound, Magnetic Flux, Length, Angular Displacement)
Organ Pipe Resonance (Frequency, Wave Length, Velocity of Sound, Length, Sound)
Photoelectric Effect (Energy, Material, Frequency, Velocity)
Quantum Theory - 1900 (Energy, Frequency, Radiation, Velocity of Light, Wave Length)
Schrodinger's Wave Equation (Linear Displacement, Energy, Frequency, Mass, Motion, Time, Wave Length)
Stoke's Law on Fluorescence (Wave Length, Frequency, Ultraviolet Light, Visible Light, Radiation)
Wien's Displacement Law (Visible Light, Radiation, Temperature, Wave Length, Frequency)
Wood & Ellett Effect (1923) (Visible Light, Ultraviolet Light, Frequency, Magnetic Flux, Polarization, Radiation)
Zeeman Effect (Color, Frequency, Visible Light, Magnetic Flux, Wave Length)

FRICTION

Johnsen-Rahbek and/or Winslow Effect (Friction, Force, Material, Voltage)
Triboelectricity (Charge, Friction, Material, Motion, Vibration, Voltage)

GAS

Adsorption (Concentration, Capacity, Gas, Material, Molecules, Surface Tension)
Graham's Law (Molecular Weight, Temperature, Concentration, Flow, Gas, Osmosis, Pressure, Solutions, Time)
Henry's Law (Gas, Weight, Volume, Solutions, Pressure, Temperature)
Ideal Gas Laws (Pressure, Partial Pressure, Gas, Temperature, Volume, Weight)

GAS (CONT)

Joule-Thomson or Joule-Kelvin Effect (Temperature, Gas, Volume, Pressure)
Paschen's Law (Gas, Length, Material, Pressure, Voltage)
Raoult's Law (Concentration, Gas, Molecular Weight, Partial Pressure, Solutions, Vapor Pressure, Boiling Point, Freezing Point)
State and Change of State (Boiling Point, Equilibrium, Freezing Point, Gas, Material, Pressure, Temperature)
Stoke's Law (Radius, Density, Gas, Motion, Temperature, Linear Velocity, Viscosity)

HEAT FLOW

Galvano-Magnetic & Thermo-Magnetic Effects (Current, Magnetic Flux, Temperature, Angle between Two Quantities, Material, Heat Flow)
Pyroelectric Effect (Charge, Electric Field, Heat Flow, Temperature, Temperature Gradient)
Stefan-Boltzmann Law (Kirchhoff's Law) (Heat Flow, Radiation, Temperature, Wave Length, Area)
Thermoelectric Effects (Heat Flow, Temperature, Thermal Conductivity, Electrical Resistance, Voltage)
Thomson & Benedick Effects (Current, Direction, Heat Flow, Material, Temperature Gradient, Voltage)
Wiedemann-Franz's Law (Heat Flow, Material, Electrical Resistance, Temperature, Thermal Conductivity)

IMPEDANCE

Impedance/Frequency (Impedance, Inductance, Capacity, Frequency)

INDEX OF REFRACTION

Faraday Effect (Magneto-Optical Rotation) (Magnetic Flux, Angular Displacement, Length, Angle between Two Quantities, Index of Refraction, Polarization, Temperature, Frequency, Wave Length, Visible Light)
Gladstone & Dale's Law (Refraction Angle, Color, Density, Index of Refraction, Material, Velocity of Light, Wave Length)
Snell's Law - 1621, The Law of Refraction (Angle of Incidence, Angle of Refraction, Index of Refraction, Visible Light, Wave Length, Density, Molecular Weights, Molecules, Temperature, Velocity of Light)
Total Reflection (Angle between Two Quantities, Angle of Reflection, Angle of Incidence, Visible Light, Index of Refraction, Material, Velocity of Light)

INDUCTANCE

Impedance/Frequency (Inductance, Capacity, Frequency, Impedance)
Skin Effect (Inductance, Current, Material, Permeability, Electrical Resistance, Temperature)

LENGTH

Ampere's Law (Force, Current, Length of Conductor, Magnetic Flux, Charge, Velocity, Angle, Voltage)
Ampere (Biot-Savart) Law (1820) (Magnetic Field, Current, Length of Conductor Linear Displacement, Angle)
Corbino Effect (Current, Length, Magnetic Field, Material)
Expansion/Temperature or Thermal Expansion (Length, Linear Displacement, Temperature, Volume)
Faraday Effect (Magneto-Optical Rotation) (Magnetic Flux, Angular Displacement, Length, Angle between Two Quantities, Index of Refraction, Polarization, Temperature, Frequency, Wave Length, Visible Light)
Ferranti Effect (Voltage, Frequency, Length)
Geiger-Nutall Rule (Energy, Linear Velocity, Length)
Hooke's Law 1678 - (Force, Area, Length, Strain and Stress)
Interference (Length, Thickness, Wave Length, Sound, Visible Light)
Kepler's Laws (Acceleration, Area, Force, Time, Length, Motion)
Magnetic Effects (Length, Motion, Permeability, Magnetic Flux)
Optical Rotary Power (Length, Material, Solution, Concentration, Wave Length, Temperature, Polarization)
Organ Pipe Resonance (Frequency, Wave Length, Velocity of Sound, Length, Sound)
Paschen's Law (Gas, Length, Material, Pressure, Voltage)
Poisson's Coefficient (or Ratio) (Linear Displacement, Length, Force, Volume)
Resistance/Dimension (Length, Electrical Resistance, Strain and Stress)

LIGHT, ULTRAVIOLET

Hertz Effect (Wiedemann & Ebert) 1887 (Visible Light, Ultraviolet Light, Charge, Radiation)
Stoke's Law on Fluorescence (Wave Length, Frequency, Ultraviolet Light, Visible Light, Radiation)
Wood & Ellett Effect - 1923 (Visible Light, Ultraviolet Light, Frequency, Magnetic Flux, Polarization, Radiation)

LIGHT, VISIBLE

Absorption (Color, Frequency, Visible Light, Radiation, Wave Length, Material)
Christiansen Effect (Wave Length, Temperature, Color, Visible Light)
Diffraction (Wave Length, Reflection Angle, Linear Displacement, X-rays, Color, Frequency, Visible Light, Radiation, Sound)
Doppler-(Fizeau) Effect 1842 (Frequency, Light, Motion, Radiation, Linear Velocity, Wave Length, Sound)
Faraday Effect (Magneto-Optical Rotation) (Magnetic Flux, Angular Displacement, Length, Angle between Two Quantities, Index of Refraction, Polarization, Temperature, Frequency, Wave Length, Visible Light)
Hertz Effect (Wiedemann & Ebert) 1887 (Visible Light, Ultraviolet Light, Charge, Radiation)
Interference (Length, Thickness, Wave Length, Sound, Visible Light)
Kerr Effect - Electrostatic (Polarization, Electric Field, Visible Light, Material, Time)
Kerr Magneto-Optic Effect (Magnetic Flux, Color, Visible Light, Material, Polarization)
Lambert's Law, Absorption Coefficient (Energy, Visible Light, Radiation, Thickness, X-rays, Solutions, Material)
Photomagnetic Effect (Current, Magnetic Flux, Permeability, Radiation, Visible Light, Temperature, Voltage)
Purkinje Effect (Color, Energy, Visible Light, Stimulus)
Radiation Pressure (Visible Light, Pressure, Radiation, Velocity of Light)
Snell's Law - 1621, The Law of Refraction (Angle of Incidence, Angle of Refraction, Index of Refraction, Visible Light, Wave Length, Density, Molecular Weights, Molecules, Temperature, Velocity of Light)
Stoke's Law on Fluorescence (Wave Length, Frequency, Ultraviolet Light, Visible Light, Radiation)
Total Reflection (Angle between Two Quantities, Angle of Reflection, Angle of Incidence, Visible Light, Index of Refraction, Material, Velocity of Light)
Wien's Displacement Law (Visible Light, Radiation, Temperature, Wave Length, Frequency)
Wood & Ellett Effect - 1923 (Visible Light, Ultraviolet Light, Frequency, Magnetic Flux, Polarization, Radiation)
Zeeman Effect (Color, Frequency, Visible Light, Magnetic Flux, Wave Length)

MAGNETIC FLUX

Ampere's Law (Force, Current, Length of Conductor, Magnetic Flux, Charge, Velocity, Angle, Voltage)
Ampere's (Biot-Savart) Law (1820) (Magnetic Field, Current, Length of Conductor, Linear Displacement, Angle)
Barkhausen Effect (Magnetic Field Intensity, Noise)
Corbino Effect (Current, Length, Magnetic Flux, Material)
Coulomb's Law (Force, Charge, Linear Displacement, Dielectric Constant, Magnetic Flux)
Curie-Weiss Law (Temperature, Magnetic Field, Material)
Faraday Effect (Magneto-Optical Rotation - 1845 (Magnetic Flux, Angular Displacement, Length, Angle between Two Quantities, Index of Refraction, Polarization, Temperature, Frequency, Wave Length, Visible Light)
Faraday's Law of Induction (Voltage, Magnetic Flux, Angular Velocity, Time, Current, Energy, Equilibrium)
Galvano-Magnetic and Thermo-Magnetic Effects (Current, Magnetic Flux, Temperature, Angle between Two Quantities, Material, Heat Flow)
Kerr Magneto-Optic Effect (Magnetic Flux, Color, Visible Light, Material, Polarization)
Magnetic Behavior of Materials (Magnetic Flux, Material)
Magnetic Effects (Length, Motion, Permeability, Magnetic Flux)
Magnetic Susceptance - Gauss Effect (Magnetic Flux, Electrical Resistance, Temperature)
Magnetostriction and Allied Effects (Force, Frequency, Material, Sound, Magnetic Flux, Length, Angular Displacement)
Photomagnetic Effect (Current, Magnetic Flux, Permeability, Radiation, Visible Light, Temperature, Voltage)
Wood & Ellett Effect - 1923 (Visible Light, Ultraviolet Light, Frequency, Magnetic Flux, Polarization, Radiation)
Zeeman Effect (Color, Frequency, Visible Light, Magnetic Flux, Wave Length)

MASS

Archimedes' Principle (287-212 BC) (Density, Specific Gravity, Volume, Mass)
Newton's Laws (Acceleration, Direction, Equilibrium, Force, Mass, Motion)
Schrodinger's Wave Equation (Linear Displacement, Energy, Frequency, Mass, Motion, Time, Wave Length)

MATERIAL

Absorption (Color, Frequency, Visible Light, Radiation, Wave Length, Material)
Adsorption (Concentration, Capacity, Gas, Material, Molecules, Surface Tension)
Corbino Effect (Current, Length, Magnetic Flux, Material)
Curie-Weiss Law (Temperature, Magnetic Field, Material)
Debye Frequency Effect (Concentration, Current, Frequency, Material, Resistance- electrical, Solution, Electrolysis)
Elastic Limit (Strain and Stress, Material)
Faraday's Law of Electrolysis - 1833 (Weight, Current, Material, Electrolysis)
Galvano-Magnetic & Thermo-Magnetic Effects (Current, Magnetic Flux, Temperature, Angle between Two Quantities, Material, Heat Flow)
Gladstone & Dale's Law (Refraction Angle, Color, Density, Index of Refraction, Material, Velocity of Light, Wave Length)
Johnsen-Rahbek and/or Winslow Effect (Friction, Force, Material, Voltage)
Kerr Effect (Electrostatic) (Polarization, Electric Field, Visible Light, Material, Time)
Kerr Magneto-Optic Effect (Magnetic Flux, Color, Visible Light, Material, Polarization)
Kohlrausch's Law (Concentration, Current, Dielectric Constant, Material, Electrical Resistance, Solutions, Temperature)
Lambert's Law Absorption Coefficient (Energy, Visible Light, Radiation, Thickness, X-rays, Solutions, Material)
Magnetic Behavior of Materials (Magnetic Flux, Material)
Magnetic Dispersion of Sound (Current, Density, Frequency, Material, Motion, Permeability, Electrical Resistance, Thickness, Velocity of Sound, Vibration, Sound)
Magnetostriction and Allied Effects (Force, Frequency, Material, Sound, Magnetic Flux, Length, Angular Displacement)
Optical Rotary Power (Length, Material, Solution, Concentration, Wave Length, Temperature, Polarization)
Paschen's Law (Gas, Length, Material, Pressure, Voltage)
Periodic Law (or Table) 1869 (Atomic Weight, Material, Radiation)
Photoelectric Effect (Energy, Material, Frequency, Velocity)
Resistance/Temperature (Electrical Resistance, Temperature, Material)
Richardson's Effect (Edison Effect) (Current, Temperature, Material, Area)
Skin Effect (Inductance, Current, Material, Permeability, Electrical Resistance, Temperature)
Stark Effect (Electric Field, Material, Voltage, Wave Length)
State and Change of State (Boiling Point, Equilibrium, Freezing Point, Gas, Material, Pressure, Temperature)
Thomson & Benedick Effects (Current, Direction, Heat Flow, Material, Temperature Gradient, Voltage)
Total Reflection (Angle between Two Quantities, Angle of Reflection, Angle of Incidence, Visible Light, Index of Refraction, Material, Velocity of Light)
Triboelectricity (Charge, Friction, Material, Motion, Vibration, Voltage)
Volta Effect (Temperature, Rectification, Material, Voltage)
Wiedemann-Franz's Law (Heat Flow, Material, Electrical Resistance, Temperature, Thermal Conductivity)
Wien Effect (Concentration, Current, Material, Electrical Resistance, Solutions, Voltage)

MOLECULAR WEIGHTS

Graham's Law (Molecular Weight, Temperature, Concentration, Flow, Gas, Osmosis, Pressure, Solutions, Time)
Raoult's Law (Concentration, Gas, Molecular Weight, Partial Pressure, Solutions, Vapor Pressure, Boiling Point, Freezing Point)
Snell's Law - 1621, The Law of Refraction (Angle of Incidence, Angle of Refraction, Index of Refraction, Visible Light, Wave Length, Density, Molecular Weights, Molecules, Temperature, Velocity of Light)

MOLECULES

Adsorption (Concentration, Capacity, Gas, Material, Molecules, Surface Tension)
Snell's Law - 1621 - The Law of Refraction (Angle of Incidence, Angle of Refraction, Index of Refraction, Visible Light, Wave Length, Density, Molecular Weights, Molecules, Temperature, Velocity of Light)

MOTION

Brownian Movement (Temperature, Motion)
Cavitation (Energy, Motion, Pressure, Temperature, Vapor Pressure, Vibration, Sound)
Doppler-(Fizeau) Effect - 1842 (Frequency, Visible Light, Motion, Radiation, Linear Velocity, Wave Length, Sound)
Kepler's Laws (Acceleration, Area, Force, Time, Length, Motion)
Magnetic Effects (Length, Motion, Permeability, Magnetic Flux)
Magnetic Dispersion of Sound (Current, Density, Frequency, Material, Motion, Permeability, Electrical Resistance, Thickness, Velocity of Sound, Vibration, Sound)
Newton's Laws (Acceleration, Direction, Equilibrium, Force, Mass, Motion)
Schrodinger's Wave Equation (Linear Displacement, Energy, Frequency, Mass, Motion, Time, Wave Length)
Shot Effect (Current, Motion, Noise, Sound, Temperature, Voltage)
Stoke's Law (Radius, Density, Gas, Motion, Temperature, Linear Velocity, Viscosity)
Triboelectricity (Charge, Friction, Material, Motion, Vibration, Voltage)

NOISE

Barkhausen Effect (Magnetic Field Intensity, Noise)
Shot Effect (Current, Motion, Noise, Sound, Temperature, Voltage)
Weber-Fechner Law (Energy, Force, Temperature, Power, Sound, Stimulus, Noise)

OSMOSIS

Graham's Law (Molecular Weight, Temperature, Concentration, Flow, Gas, Osmosis, Pressure, Solutions, Time)

PERMEABILITY

Magnetic Effects (Length, Motion, Permeability, Magnetic Flux)
Magnetic Dispersion of Sound (Current, Density, Frequency, Material, Motion, Permeability, Electrical Resistance, Thickness, Velocity of Sound, Vibration, Sound)
Photomagnetic Effect (Current, Magnetic Flux, Permeability, Radiation, Visible Light, Temperature, Voltage)
Skin Effect (Inductance, Current, Material, Permeability, Electrical Resistance, Temperature)

POLARIZATION (OPTICS)

Brewster's Law (Refraction Angle, Polarization, Reflection Angle, Wave Length, Frequency)
Faraday Effect (Magneto-Optical Rotation) (Magnetic Flux, Angular Displacement, Length, Angle between Two Quantities, Index of Refraction, Polarization, Temperature, Frequency, Wave Length, Visible Light)
Kerr Effect - Electrostatic (Polarization, Electric Field, Visible Light, Material, Time)
Kerr Magneto-Optic Effect (Magnetic Flux, Color, Visible Light, Material, Polarization)
Optical Rotary Power (Length, Material, Solution, Concentration, Wave Length, Temperature, Polarization)
Wood & Ellett Effect - 1923 (Visible Light, Ultraviolet Light, Frequency, Magnetic Flux, Polarization, Radiation)

POSITION (GEOGRAPHICAL)

Cosmic Rays (Geographical Position, Altitude, Incidence Angle, Concentration, Direction, Energy, Radiation)
Eotvos Effect (Geographic Position, Weight, Linear Velocity)

POWER

Weber-Fechner Law (Energy, Force, Temperature, Power, Sound, Stimulus, Noise)

PRESSURE

Bernoulli Theorem (Altitude, Pressure, Density, Velocity, Flow)
Cavitation (Energy, Motion, Pressure, Temperature, Vapor Pressure, Vibration, Sound)
Electrocapillarity (Pressure, Voltage, Surface Tension, Flow)
Electrokinetic Phenomena (Acceleration, Current, Flow, Pressure, Voltage)
Gibbs Theory of Equilibria Phase Rule (Pressure, Temperature, Concentration)
Graham's Law (Molecular Weight, Temperature, Concentration, Flow, Gas, Osmosis, Pressure, Solutions, Time)
Henry's Law (Gas, Weight, Volume, Solutions, Pressure, Temperature)
Ideal Gas Laws (Pressure, Partial Pressure, Gas, Temperature, Volume, Weight)
Joule-Thomson or Joule-Kelvin Effect (Pressure, Temperature, Gas, Volume, Pressure)
LeChatelier's Law (Concentration, Equilibrium, Pressure, Temperature)
Paschen's Law 1889 (Gas, Length, Material, Pressure, Voltage)
Pinch Effect (Area, Current, Force, Pressure, Electrical Resistance, Temperature)
Radiation Pressure (Visible Light, Pressure, Radiation, Velocity of Light)
State and Change of State (Boiling Point, Equilibrium, Freezing Point, Gas, Material, Pressure, Temperature)
Surface Tension (Pressure, Surface Tension, Force, Radius)

PRESSURE, PARTIAL

Ideal Gas Laws (Pressure, Partial Pressure, Gas, Temperature, Volume, Weight)
Raoult's Law (Concentration, Gas, Molecular Weight, Partial Pressure, Solutions, Vapor Pressure, Boiling Point, Freezing Point)

RADIATION

Absorption (Color, Frequency, Visible Light, Radiation, Wave Length, Material)
Boltzmann Distribution Law (Energy, Radiation, Temperature)
Bremstrahlung Radiation (Acceleration, Density, Electric Field, Energy, Frequency, Radiation, Voltage, X-rays)
Cosmic Rays (Geographic Position, Altitude, Incidence Angle, Concentration, Direction, Energy, Radiation)
Diffraction (Wave Length, Reflection Angle, Linear Displacement, X-rays, Color, Frequency, Visible Light, Radiation, Sound)
Doppler-(Fizeau) Effect 1842 (Frequency, Visible Light, Motion, Radiation, Linear Velocity, Wave Length, Sound)
Fission (Atomic Weight, Energy, Radiation)
Group Displacement Law (Atomic Weight, Charge, Energy, Radiation, Time, X-rays)
Hertz Effect (Wiedemann & Ebert) 1887 (Visible Light, Ultraviolet Light, Charge, Radiation)
Lambert's Law, Absorption Coefficient (Energy, Visible Light, Radiation, Thickness, X-rays, Solutions, Material)
Period Law (or Table) 1869 (Atomic Weight, Material, Radiation)
Photomagnetic Effect (Current, Magnetic Flux, Permeability, Radiation, Visible Light, Temperature, Voltage)
Quantum Theory - 1900 (Energy, Frequency, Radiation, Velocity of Light, Wave Length)
Radiation Pressure (Visible Light, Pressure, Radiation, Velocity of Light)
Radioactivity (Charge, Energy, Radiation, X-rays)
Stefan-Boltzmann Law (Kirchhoff's Law) (Heat Flow, Radiation, Temperature, Wave Length, Area)
Stoke's Law on Fluorescence (Wave Length, Frequency, Ultraviolet Light, Visible Light, Radiation)
Wien's Displacement Law (Visible Light, Radiation, Temperature, Wave Length, Frequency)
Wood & Ellett Effect - 1923 (Visible Light, Ultraviolet Light, Frequency, Magnetic Flux, Polarization, Radiation)

RADIUS

Kelvin's Principle for Fluid Drops (Density, Equilibrium, Radius, Surface Tension, Temperature, Vapor Pressure)
Proximity Effect (Current, Electric Field, Radius, Electrical Resistance)
Surface Tension (Pressure, Surface Tension, Force, Radius)
Stoke's Law (Radius, Density, Gas, Motion, Temperature, Linear Velocity, Viscosity)

RECTIFICATION

Volta Effect (Temperature, Rectification, Material, Voltage)

RESISTANCE, ELECTRICAL

Debye Frequency Effect (Concentration, Current, Frequency, Material, Resistance- electrical, Solution, Electrolysis)
Joule's Law (Resistance, Current, Time, Energy)
Kohlrausch's Law (Concentration, Current, Dielectric Constant, Material, Electrical Resistance, Solutions, Temperature)
Magnetic Dispersion of Sound (Current, Density, Frequency, Material, Motion, Permeability, Electrical Resistance, Thickness, Velocity of Sound, Vibration, Sound)
Magnetic Susceptance - Gauss Effect (Magnetic Flux, Electrical Resistance, Temperature)
Ohm's Law (Current, Electrical Resistance, Voltage)
Pinch Effect (Area, Current, Force, Pressure, Electrical Resistance, Temperature)
Proximity Effect (Current, Electric Field, Radius, Electrical Resistance)
Resistance/Dimension (Length, Electrical Resistance, Strain & Stress)
Resistance/Temperature (Electrical Resistance, Temperature, Material)
Skin Effect (Inductance, Current, Material, Permeability, Electrical Resistance, Temperature)
Thermoelectric Effects (Heat Flow, Temperature, Thermal Conductivity, Electrical Resistance, Voltage)
Wiedemann-Franz's Law (Heat Flow, Material, Electrical Resistance, Temperature, Thermal Conductivity)
Wien Effect (Concentration, Current, Material, Electrical Resistance, Solutions, Voltage)

SOLUTIONS

Arrhenius Theory of Electrolytic Dissociation (Solute, Solvent, Freezing Point, Boiling Point
Debye Frequency Effect (Concentration, Current, Frequency, Material, Resistance-electrical, Solution, Electrolysis)

SOLUTIONS (CONT)

Fick's Law (Solutions, Time, Temperature, Area, Concentration, Voltage)
Graham's Law (Molecular Weight, Temperature, Concentration, Flow, Gas, Osmosis, Pressure, Solutions, Time)
Henry's Law (Gas, Weight, Volume, Solutions, Pressure, Temperature)
Kohlrausch's Law (Concentration, Current, Dielectric Constant, Material, Electrical Resistance, Solutions, Temperature)
Lambert's Law, Absorption Coefficient (Energy, Visible Light, Radiation, Thickness, X-rays, Solutions, Materials)
Optical Rotary Power (Length, Material, Solution, Concentration, Wave Length, Temperature, Polarization)
Raoult's Law (Concentration, Gas, Molecular Weight, Partial Pressure, Solutions, Vapor Pressure, Boiling Point, Freezing Point)
Wien Effect (Concentration, Current, Material, Electrical Resistance, Solutions, Voltage)

SOUND

Cavitation (Energy, Motion, Pressure, Temperature, Vapor Pressure, Vibration, Sound)
Diffraction (Wave Length, Reflection Angle, Linear Displacement, X-rays, Color, Frequency, Visible Light, Radiation, Sound)
Doppler-(Fizeau) Effect (1842) (Frequency, Visible Light, Motion, Radiation, Linear Velocity, Wave Length, Sound)
Interference (Length, Thickness, Wave Length, Sound, Visible Light)
Magnetic Dispersion of Sound (Current, Density, Frequency, Material, Motion, Permeability, Electrical Resistance, Thickness, Velocity of Sound, Vibration, Sound)
Magnetostriction and Allied Effects (Force, Frequency, Material, Sound, Magnetic Flux, Length, Angular Displacement)
Organ Pipe Resonance (Frequency, Wave Length, Velocity of Sound, Length, Sound)
Shot Effect (Current, Motion, Noise, Sound, Temperature, Voltage)
Weber-Fechner Law (Energy, Force, Temperature, Power, Sound, Stimulus, Noise)

SPECIFIC HEAT

Constant Heat Capacity Law (Atomic Weight, Specific Heat)

SPECIFIC GRAVITY

Archimedes' Principle (287-212 BC) (Density, Specific Gravity, Volume, Mass)

STIMULUS

Purkinje Effect (Color, Energy, Visible Light, Stimulus)
Weber-Fechner Law (Energy, Force, Temperature, Power, Sound, Stimulus, Noise)

STRAIN AND STRESS

Bauschinger Effect (Linear Displacement, Elastic Limit, Force, Strain and Stress, Temperature)
Elastic Limit (Strain and Stress, Material)
Hooke's Law - 1678 (Force, Area, Length, Strain and Stress)
Resistance/Dimension (Length, Electrical Resistance, Strain and Stress)
Thermoelastic Effect (Force, Strain and Stress, Temperature Gradient, Voltage)

SURFACE TENSION

Adsorption (Concentration, Capacity, Gas, Material, Molecules, Surface Tension)
Electrocapillarity (Pressure, Voltage, Surface Tension, Flow)
Kelvin's Principle for Fluid Drops (Density, Equilibrium, Radius, Surface Tension, Temperature, Vapor Pressure)
Surface Tension (Pressure, Surface Tension, Force, Radius)

TEMPERATURE

Bauschinger Effect (Linear Displacement, Elastic Limit, Force, Strain and Stress, Temperature)
Boltzmann Distribution Law (Energy, Radiation, Temperature)
Brownian Movement (Temperature, Motion)
Capacity/Dielectric (Charge, Capacitance, Voltage, Dielectric Constant, Linear Displacement, Temperature, Thickness)
Cavitation (Energy, Motion, Pressure, Temperature, Vapor Pressure, Vibration, Sound)
Christiansen Effect (Wave Length, Temperature, Color, Visible Light)
Curie-Weiss Law (Temperature, Magnetic Field, Material)
Expansion/Temperature or Thermal Expansion (Length, Linear Displacement, Temperature, Volume)
Faraday Effect (Magneto-Optical Rotation) (Magnetic Flux, Angular Displacement, Length, Angle between Two Quantities, Index of Refraction, Polarization, Temperature, Frequency, Wave Length, Visible Light)
Fick's Law (Solutions, Time, Temperature, Area, Concentration, Voltage)

TEMPERATURE (CONT)

Galvano-Magnetic and Thermo-Magnetic Effects (Current, Magnetic Flux, Temperature, Angle between Two Quantities, Material, Heat Flow)
Gibbs Theory of Equilibria - Phase Rule (Pressure, Temperature, Concentration)
Graham's Law (Molecular Weight, Temperature, Concentration, Flow, Gas, Osmosis, Pressure, Solutions, Time)
Henry's Law (Gas, Weight, Volume, Solutions, Pressure, Temperature)
Ideal Gas Laws (Pressure, Partial Pressure, Gas, Temperature, Volume, Weight)
Joule-Thomson or Joule-Kelvin Effect (Pressure, Temperature, Gas, Volume)
Kelvin's Principle for Fluid Drops (Density, Equilibrium, Radius, Surface Tension, Temperature, Vapor Pressure)
Kohlrausch's Law (Concentration, Current, Dielectric Constant, Material, Electrical Resistance, Solutions, Temperature)
Le Chatelier's Law (Concentration, Equilibrium, Pressure, Temperature)
Magnetic Susceptance - Gauss Effect (Magnetic Flux, Electrical Resistance, Temperature)
Optical Rotary Power (Length, Material, Solution, Concentration, Wave Length, Temperature, Polarization)
Photomagnetic Effect (Current, Magnetic Flux, Permeability, Radiation, Visible Light, Temperature, Voltage)
Pinch Effect (Area, Current, Force, Pressure, Resistance, Temperature)
Pyroelectric Effect (Charge, Electric Field, Heat Flow, Temperature, Temperature Gradient)
Resistance/Temperature (Electrical Resistance, Temperature, Material)
Richardson's Effect (Temperature, Area, Material, Current)
Shot Effect (Current, Motion, Noise, Sound, Temperature, Voltage)
Skin Effect (Inductance, Current, Material, Permeability, Electrical Resistance, Temperature)
Snell's Law - 1621 - The Law of Refraction (Angle of Incidence, Angle of Refraction, Index of Refraction, Visible Light, Wave Length, Density, Molecular Weights, Molecules, Temperature, Velocity of Light)
State and Change of State (Boiling Point, Equilibrium, Freezing Point, Gas, Material, Pressure, Temperature)
Stefan-Boltzmann Law (Kirchhoff's Law) (Heat Flow, Radiation, Temperature, Wave Length, Area)
Stoke's Law (Radius, Density, Gas, Motion, Temperature, Linear Velocity, Viscosity)
Thermoelectric Effects (Heat Flow, Temperature, Thermal Conductivity, Electrical Resistance, Voltage)
Volta Effect (Temperature, Rectification, Material, Voltage)
Weber-Fechner Law (Energy, Force, Temperature, Power, Sound, Stimulus, Noise)
Wiedemann-Franz's Law (Heat Flow, Material, Electrical Resistance, Temperature, Thermal Conductivity)
Wien's Displacement Law (Visible Light, Radiation, Temperature, Wave Length, Frequency)

TEMPERATURE GRADIENT

Pyroelectric Effect (Charge, Electric Field, Heat Flow, Temperature, Temperature Gradient)
Thermoelastic Effect (Force, Strain and Stress, Temperature Gradient, Voltage)
Thomson & Benedick Effects (Current, Direction, Heat Flow, Material, Temperature Gradient, Voltage)

THERMAL CONDUCTIVITY

Thermoelectric Effects (Heat Flow, Temperature, Thermal Conductivity, Electrical Resistance, Voltage)
Wiedemann-Franz's Law (Heat Flow, Material, Electrical Resistance, Temperature, Thermal Conductivity)

THICKNESS

Capacity/Dielectric (Charge, Capacitance, Voltage, Dielectric Constant, Linear Displacement, Temperature, Thickness)
Interference (Length, Thickness, Wave Length, Sound, Visible Light)
Lambert's Law, Absorption Coefficient (Energy, Visible Light, Radiation, Thickness, X-rays, Solutions, Material)
Magnetic Dispersion of Sound (Current, Density, Frequency, Material, Motion, Permeability, Electrical Resistance, Thickness, Velocity of Sound, Vibration, Sound)

TIME

Faraday's Law of Induction (Voltage, Magnetic Flux, Angular Velocity, Time, Current, Energy, Equilibrium)
Fick's Law (Solutions, Time, Temperature, Area, Concentration, Voltage)
Graham's Law (Molecular Weight, Temperature, Concentration, Flow, Gas, Osmosis, Pressure, Solutions, Time)

TIME (CONT)
Group Displacement Law (Atomic Weight, Charge, Energy, Radiation, Time, X-rays)
Joule's Law (Resistance, Current, Time, Energy)
Kepler's Laws (Acceleration, Area, Force, Time, Length, Motion)
Kerr Effect - Electrostatic (Polarization, Electric Field Visible Light, Material, Time)
Residual Voltage (Charge, Current, Voltage, Time)
Schrodinger's Wave Equation (Linear Displacement, Energy, Frequency, Mass, Motion, Time, Wave Length)

VAPOR PRESSURE
Cavitation (Energy, Motion, Pressure, Temperature, Vapor Pressure, Vibration, Sound)
Kelvin's Principle for Fluid Drops (Density, Equilibrium, Radius, Surface Tension, Temperature, Vapor Pressure)
Raoult's Law (Concentration, Gas, Molecular Weight, Partial Pressure, Solutions, Vapor Pressure, Boiling Point, Freezing Point)

VELOCITY, ANGULAR
Faraday's Law of Induction (Voltage, Magnetic Flux, Angular Velocity, Time, Current, Energy, Equilibrium)

VELOCITY, LINEAR
Ampere's Law (Force, Current, Length of Conductor, Magnetic Flux, Charge, Velocity, Angle, Voltage)
Bernoulli Theorem (Altitude, Pressure, Density, Velocity, Flow)
Doppler- (Fizeau) Effect (1842) (Frequency, Visible Light, Motion, Radiation, Linear Velocity, Wave Length, Sound)
Eotvos Effect (Geographical Position, Linear Velocity, Weight)
Geiger-Nutall Rule (Energy, Linear Velocity, Length)
Stoke's Law (Radius, Density, Gas, Motion, Temperature, Linear Velocity, Viscosity)

VELOCITY OF LIGHT
Gladstone & Dale's Law (Refraction Angle, Color, Density, Index of Refraction, Material, Velocity of Light, Wave Length)
Photoelectric Effect (Energy, Material, Frequency, Velocity of Light)
Quantum Theory 1900 (Energy, Frequency, Radiation, Velocity of Light, Wave Length)
Radiation Pressure (Visible Light, Pressure, Radiation, Velocity of Light)
Snell's Law - 1621 - The Law of Refraction (Angle of Incidence, Angle of Refraction, Index of Refraction, Visible Light, Density, Molecular Weights, Molecules, Temperature, Velocity of Light)
Total Reflection (Angle between Two Quantities, Angle of Reflection, Angle of Incidence, Visible Light, Index of Refraction, Material, Velocity of Light)

VELOCITY OF SOUND
Magnetic Dispersion of Sound (Current, Density, Frequency, Material, Motion, Permeability, Electrical Resistance, Thickness, Velocity of Sound, Vibration, Sound)
Organ Pipe Resonance (Frequency, Wave Length, Velocity of Sound, Length, Sound)

VIBRATION
Cavitation (Energy, Motion, Pressure, Temperature, Vapor Pressure, Vibration, Sound)
Magnetic Dispersion of Sound (Current, Density, Frequency, Material, Motion, Permeability, Electrical Resistance, Thickness, Velocity of Sound, Vibration, Sound)
Piezoelectric Effect (Charge, Force, Voltage, Vibration, Energy)
Triboelectricity (Charge, Friction, Material, Motion, Vibration, Voltage)

VISCOSITY
Stoke's Law (Radius, Density, Gas, Motion, Temperature, Linear Velocity, Viscosity)

VOLTAGE
Ampere's Law (Force, Current, Length of Conductor, Magnetic Flux, Charge, Velocity, Angle, Voltage)
Bremstrahlung Radiation (Acceleration, Density, Electric Field, Energy, Frequency, Radiation, Voltage, X-rays)
Capacity/Dielectric (Charge, Capacity, Voltage, Dielectric Constant, Linear Displacement, Temperature, Thickness)
Electrocapillarity (Pressure, Voltage, Surface Tension, Flow)
Electrokinetic Phenomena (Acceleration, Current, Flow, Pressure, Voltage)
Faraday's Law of Induction (Voltage, Magnetic Flux, Angular Velocity, Time, Current, Energy, Equilibrium)
Ferranti Effect (Voltage, Frequency, Length)
Fick's Law (Solutions, Time, Temperature, Area, Concentration, Voltage)
Johnsen-Rahbek and/or Winslow Effect (Friction, Force, Material, Voltage)
Kirchhoff's Laws (Current, Voltage)
Ohms Law (Current, Resistance, Voltage)

VOLTAGE (CONT)

Paschen's Law (Voltage, Gas, Length, Pressure, Material)
Photomagnetic Effect (Current, Magnetic Flux, Permeability, Radiation, Visible Light, Temperature, Voltage)
Piezoelectric Effect (Voltage, Charge, Vibration, Force, Energy)
Residual Voltage (Charge, Current, Voltage, Time)
Shot Effect (Time, Current, Motion, Noise, Sound, Temperature, Voltage)
Stark Effect (Electric Field, Material, Voltage, Wave Length)
Thermoelastic Effect (Force, Strain and Stress, Temperature Gradient, Voltage)
Thermoelectric Effects (Heat Flow, Temperature, Thermal Conductivity, Electrical Resistance, Voltage)
Thomson & Benedick Effects (Current, Direction, Heat Flow, Material, Temperature Gradient, Voltage)
Triboelectricity (Charge, Friction, Material, Motion, Vibration, Voltage)
Volta Effect (Temperature, Rectification, Material, Voltage)
Wien Effect (Concentration, Current, Material, Electrical Resistance, Solutions, Voltage)

VOLUME

Archimedes' Principle (287-212 BC) (Density, Specific Gravity, Volume, Mass)
Expansion/Temperature or Thermal Expansion (Length, Linear Displacement, Temperature, Volume)
Henry's Law (Gas, Weight, Volume, Solutions, Pressure, Temperature)
Ideal Gas Laws (Pressure, Partial Pressure, Gas, Temperature, Volume, Weight)
Joule-Thomson or Joule-Kelvin Effect (Temperature, Gas, Volume, Pressure)
Poisson's Coefficient (or Ratio) (Linear Displacement, Force, Length, Volume)

WAVE LENGTH

Absorption (Color, Frequency, Visible Light, Radiation, Wave Length, Material)
Brewster's Law (Refraction Angle, Polarization, Reflection Angle, Wave Length, Frequency)
Christiansen Effect (Wave Length, Temperature, Color, Visible Light)
Compton Effect (1923) (X-rays, Wave Length)
Diffraction (Wave Length, Reflection Angle, Linear Displacement, X-rays, Color, Frequency, Visible Light, Radiation, Sound)
Doppler- (Fizeau) Effect (Frequency, Visible Light, Motion, Radiation, Linear Velocity, Wave Length, Sound)
Faraday Effect (Magneto-Optical Rotation) (Magnetic Flux, Angular Displacement, Length, Angle between Two Quantities, Index of Refraction, Polarization, Temperature, Frequency, Wave Length, Visible Light)
Gladstone & Dale's Law (Refraction Angle, Color, Density, Index of Refraction, Material, Velocity of Light, Wave Length)
Interference (Length, Thickness, Wave Length, Sound, Visible Light)
Optical Rotary Power (Length, Material, Solution, Concentration, Wave Length, Temperature, Polarization)
Organ Pipe Resonance (Frequency, Wave Length, Velocity of Sound, Length, Sound)
Quantum Theory - 1900 (Energy, Frequency, Radiation, Velocity of Light, Wave Length)
Schrodinger's Wave Equation (Linear Displacement, Energy, Frequency, Mass, Motion, Time, Wave Length)
Snell's Law - 1621, The Law of Refraction (Angle of Incidence, Angle of Refraction, Index of Refraction, Visible Light, Wave Length, Density, Molecular Weights, Molecules, Temperature, Velocity of Light)
Stark Effect (Electric Field, Material, Voltage, Wave Length)
Stefan-Boltzmann (Kirchhoff's Law) (Heat Flow, Radiation, Temperature, Wave Length, Area)
Stoke's Law on Fluorescence (Wave Length, Frequency, Ultraviolet Light, Visible Light, Radiation)
Wien's Displacement Law (Visible Light, Radiation, Temperature, Wave Length, Frequency)
Zeeman Effect (Color, Frequency, Visible Light, Magnetic Flux, Wave Length)

WEIGHT

Eotvos Effect (Geographical Position, Weight, Linear Velocity)
Faraday's Law of Electrolysis- 1833 (Weight, Current, Material, Electrolysis)
Henry's Law (Gas, Weight, Volume, Solutions, Pressure, Temperature)
Ideal Gas Laws (Pressure, Partial Pressure, Gas, Temperature, Volume, Weight)

X-RAYS

Bremstrahlung Radiation (Acceleration, Density, Electric Field, Energy, Frequency, Radiation, Voltage, X-rays)
Compton Effect (1923) (Wave Length, X-rays)
Diffraction (Wave Length, Reflection Angle, Linear Displacement, X-rays, Color, Frequency, Visible Light, Radiation, Sound)
Group Displacement Law (Atomic Weight, Charge, Energy, Radiation, Time, X-rays)
Lambert's Law, Absorption Coefficient (Energy, Visible Light, Radiation, Thickness, X-rays, Solutions, Material)
Radioactivity (Charge, Energy, Radiation, X-rays)